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Management of Small-Stem Stands of Lodgepole Pine—Workshop Proceedings

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The Management Challenge

Chaired by: Roland L. Barger

Small lodgepole pine—especially subsawtimber pole stands of young or older stagnated trees—presents a significant management challenge across much of the Inland West. Lodgepole pine occurs in quantity in eight western States and is the principal species in more than a dozen National Forests. In addition to representing a wood fiber resource, small lodgepole pine occupies lands important for watershed, wildlife, recreation, and other uses. Effective multiresource management of these lands is essential. Information presented in this section describes the extent and character of the resource, and discusses management issues and options.

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EXTENT AND CHARACTER OF SMALL-STEM LODGEPOLE PINE STANDS IN THE MOUNTAIN WEST

Carl E. Fiedler

ABSTRACT: Lodgepole pine (var. latifolia) is one of the most widely distributed pines in western North America, extending from southern Colorado north to the central Yukon, and from 1,500 to 11,500 feet in elevation. This paper focuses on stands below sawtimber size (<9.0 inches diameter at breast height [d.b.h.]). About 4.5 million of the 12.6 million acres of lodgepole pine in the Mountain West are classified in this submerchantable category. Typically, small-stem lodgepole pine stands are of fire origin, over 50 years old, and moderately to heavily overstocked. Maturing stands with >2,000 trees per acre (tpa) are unlikely to yield traditional sawtimber-size trees (>9 inches d.b.h.), and stands with >3,000 tpa will produce few stems >7 inches d.b.h. Overstocked lodgepole pine are tall relative to their diameter, cylindrical, uniform in size, and have short crowns with small branches. These characteristics correspond well with roundwood uses.

INTRODUCTION

Some years ago, Hutchison (1964) reported that "the popular impression of lodgepole pine is of a skinny tree growing out on the edge of nowhere." He noted that this was probably an apt description of lodgepole pine (Pinus contorta Dougl. ex Loud.) forests, as well as a primary source of the economic problems limiting large-scale utilization of this species.

Only recently have developments in harvesting technology and widespread availability of specialized equipment for harvesting and processing small trees allowed increased utilization of lodgepole pine. Two factors have been largely responsible for bringing about these changes. First, a dwindling old-growth timber supply in the West has shifted emphasis toward increased utilization of smaller diameter material such as lodgepole pine. Second, and probably more important, what traditionally has been only casual interest in lodgepole pine forests has evolved, due to the recent mountain pine beetle (Dendroctonus ponderosae Hopkins) epidemic, into critical concern about the future of this resource. The beetle epidemic has brought about a sharply accelerated harvest program to salvage existing and imminent mortality, and has heightened awareness of the importance of actively managing lodgepole pine to prevent similar large-scale epidemics in the future. Lack of management in the past, for whatever reason, has left today's manager in the unenviable position of having to react to crises, rather than being able to direct stand development by applying appropriate intermediate treatments. Improved utilization opportunities in the future could make the latter scenario a reality.

The purposes of this report are (1) to describe the extent of the lodgepole pine resource in the Mountain West in terms of acreage, location, and availability, and (2) to describe the character of lodgepole pine in terms of the biological and physical attributes that affect stand development and utilization.

EXTENT

The mountain variety of lodgepole pine (var. latifolia) is one of the most widely distributed pines in western North America, extending from southern Colorado north to the central Yukon, and from 1,500 to 11,500 feet in elevation (fig. 1). Lodgepole pine forests occupy about 12.4 million acres within the United States portion of this broad geographical area (Barger and Fiedler 1982). These forests contain about 25 billion cubic feet of growing stock and 65 billion cubic feet of sawtimber, approximately two-thirds of which is in Montana, Idaho, and Oregon (Lotan and Perry 1983). However, this report focuses on only a subset of the lodgepole pine resource--stands below traditional sawtimber size (0.1 to 8.9 inches diameter at breast height [d.b.h.])--hereafter referred to as small-stem stands.

About 5.7 million acres of lodgepole pine in the Mountain West are classified as poletimber (5.0 to 8.9 inches d.b.h.), and more than 1.9 million acres as saplings/seedlings (0.1 to 4.9 inches d.b.h.) (table 1). An unknown additional amount of lodgepole pine poletimber and saplings/seedlings occurs in the Pine Subregion of eastern Oregon and eastern Washington. Assuming that these two size classes comprise the same proportion of the lodgepole pine resource there as in the Northern Rocky Mountains, then the total area occupied by small-stem stands in the Mountain West exceeds 7.6 million acres.

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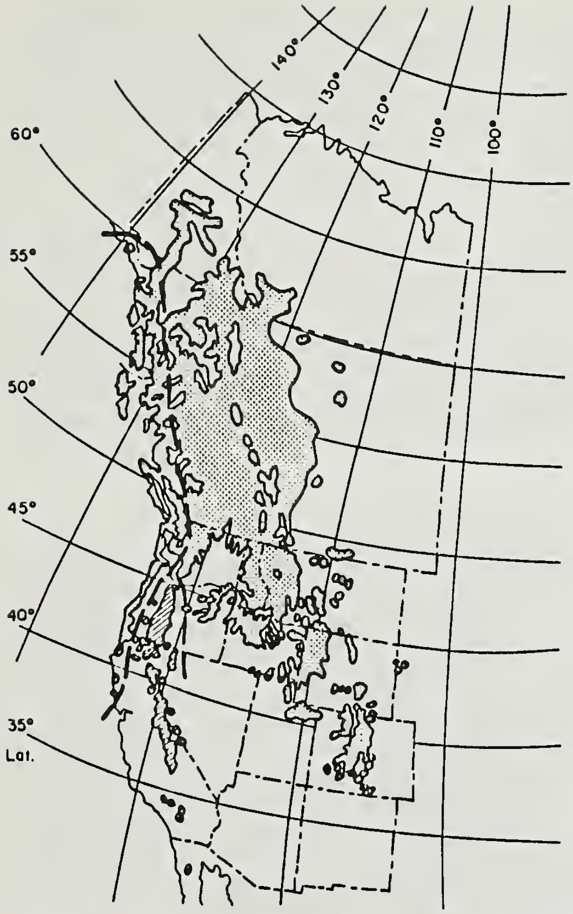

Figure 1--The range of lodgepole pine extends from southern Colorado to the central Yukon. The mountain variety (var. latifolia) is shown to the right of the dashed lines.

The problem with these estimates from the standpoint of utilization is that they are developed from Continuous Forest Inventory data, and cannot be disaggregated into acreage estimates for individual small-stem stands and specific locations. Furthermore, stand level information that may be needed to promote utilization is usually not available because stand examination inventories have generally not been done (Fiedler and others [review draft]).

From the standpoint of utilization, the extent of the lodgepole pine resource is the acreage available for harvest, rather than the physical supply, and the two are quite different. The acreage of small-stem stands that is actually available for utilization is not precisely known, but it is significantly less than the estimated physical supply of 7.6 million acres. Availability is affected by three major factors:

1. Administrative classifications and constraints
2. Terrain
3. Distance to roads.

Administrative Classifications and Constraints

Large acreages of commercial forest land in the Mountain West have been placed in productive reserved or deferred land use classes. Productive reserved lands are those included in wilderness areas, administrative sites, natural areas, and other classifications that preclude all harvesting activity. For example, extensive stands of lodgepole pine provide the dominant backdrop in numerous national parks, wilderness areas, and other areas of scenic and recreational importance. Consequently, about 4.3 million acres of

Table 1--Area of lodgepole pine in the Mountain West by region, State, and size class[1]

Location	Sawtimber $\leq$9.0 inches d.b.h.	Poletimber 5.0 to 8.9 inches d.b.h.	Saplings/seedlings 0.1 to 4.9 inches d.b.h.	Total
	Thousand acres			
Northern Rocky Mountains				
Montana	1,632.8	2,450.5	742.3	4,825.6
Idaho	905.3	772.6	606.9	2,284.8
Wyoming	557.5	521.1	70.7	1,149.3
Total	3,095.6	3,744.2	1,419.9	8,259.7
Southern Rocky Mountains				
Colorado	459.0	584.7	83.0	1,126.7
Utah	272.4	220.8	37.7	530.9
Nevada	5.8	0	0	5.8
Total	737.2	805.5	120.7	1,663.4
Rocky Mountain Total	3,832.8	4,549.7	1,540.6	9,923.1
Pine Subregion				
Eastern Oregon and Eastern Washington	[2]935.1	1,131.0	428.9	2,495.0
Mountain West Total	4,767.9	5,680.7	1,969.5	12,418.1

[1]Summarized from Green and Setzer (1974) and USDA FS (1978).
[2]Only total acreage of lodgepole pine was available for the Pine Subregion. Acreage estimates of sawtimber, poletimber, and saplings/seedlings were developed using proportions by size class for the Northern Rocky Mountains.

the entire 12.4-million-acre lodgepole pine resource has been placed within productive reserved or deferred land use classes, thereby precluding timber harvest (Barger and Fiedler 1982). Assuming that the proportion of the total lodgepole pine acreage that falls under these restrictions applies equally to small-stem stands, about 2.6 million acres are in reserved or deferred status.

Availability is further limited on public lands by policies and regulations that place harvesting constraints on some stands that are otherwise available. Availability in these cases depends less upon characteristics of the individual stand than upon the larger environment within which the stand occurs. Examples include limits on the proportion of a watershed that can be harvested within a given period, constraints on activities within threatened and endangered species habitat, and constraints on road development due to soils problems or water quality concerns. Thus, the proportion of the small-stem lodgepole pine acreage within an administrative unit that is actually available for harvest at a given time may be relatively small, and not sufficient to supply large-scale proposed uses.

Coston (1985) reports that reliable figures will not be known on the supply of lodgepole pine available for timber harvest until decisions are made about which areas will be added to the National Wilderness Preservation System, and what special considerations will limit standard harvests in other critical areas.

Terrain

A survey of national forests in the Mountain West with significant lodgepole pine acreage found that 25 percent of this resource is located on terrain too steep for conventional tractor logging (Benson and others [review draft]), thus requiring high-cost harvesting systems. Gonsior and Johnson (1985) reported that lodgepole pine's relatively small size and low value do not lend it well either to high-cost, ground-based logging equipment or to cable harvest on steep terrain, because piece size is generally inversely related to harvest cost. Conversely, low-cost and reduced-size harvesting systems are not yet efficient enough to offset smaller piece size and keep harvest costs constant per unit of output.

Depending on the situation, these factors may result in a significant reduction of the acreage of small-stem lodgepole pine actually available for harvest. Harvesting lodgepole pine on steep terrain may also require dealing with such factors as difficult and costly access, environmental constraints, and multiple-use considerations.

Distance to Roads

The issue of access and road-building needs in western forests is probably nowhere more acute than in the lodgepole pine type. Lack of adequate transportation systems is a primary obstacle to the solution of utilization problems in this forest type (Hutchison 1964). Benson and others (review draft) reported that an estimated 65 percent of small-stem stands in the Forest Service's Northern Region are accessed, while only 20 percent are accessed in the Intermountain Region. Hutchison (1964) estimated that at the present rate of road building in the lodgepole pine type, only 60 percent of the necessary road system would be in place by the year 2000.

In spite of the significant reductions in, and restrictions on, the physical supply of lodgepole pine, available supply exceeds demand in most areas. The prevailing view is that the principal barrier to utilizing available small-stem stands is financial; that is, the cost of harvesting and processing the material in these stands exceeds the value of products recovered (Barger 1982).

TREE CHARACTERISTICS

Lodgepole pine trees in overstocked stands are tall relative to their diameter, uniform in size, with thin bark, short crowns, and small limbs. The size, bole form, and treating and machining characteristics of small-stem lodgepole pine correspond well with roundwood uses (for example, posts, poles, tree props, and grape stakes) (Coston 1985). Ironically, better management and earlier density control would compromise some of the desirable utilization attributes unique to small-stem lodgepole pine. The fact that lodgepole pine dries well, is light in weight, and contains small tight knots also makes it competitive with other species for manufacture into sawn products (Van Hooser and Keegan 1985). For example, in 1981, lodgepole pine comprised 31 percent of the timber processed into lumber in Montana, more than any other species (Keegan and others 1983).

STAND CHARACTERISTICS

Stands that comprise the small-stem lodgepole pine resource have several distinguishing characteristics: a vast majority originated from wildfire, most are over 50 years old, and most are moderately to heavily overstocked. It is evident from the last two characteristics that trees in these stands are small because of overstocking, not because they are young. Managers are currently faced with a dilemma in deciding what to do with such stands. Despite the fact that most small-stem stands are "below-cost" chances from a harvesting standpoint, there are several compelling reasons for wanting to extend utilization and management into these stands.

First, maturing stands with >2,000 trees per acre (tpa) will yield few trees ≥9 inches d.b.h., and stands with >3,000 tpa are unlikely to yield many trees ≥7 inches d.b.h.

Second, volume yield of severely overstocked stands may be far below site potential. Smithers (1961) presented an example of the effect of overstocking on volume production for two lodgepole pine stands in Alberta. These stands were located less than 200 feet apart on a flat bench,

and showed no difference in soil profile or texture.

Characteristics	Stand 1	Stand 2
Age (yr)	75	60
Density (tpa)	9,000	860
Diameter (inches)	1.8	6.0
Basal area (ft^2)	161	167
Height (ft)	33	58
Volume (ft^3)	1,757	4,440

Conclusions that can be drawn from these data are that very high density has little effect on either basal area carrying capacity or gross increment in basal area. However, cubic volume, because of its dependence on average height, is greatly reduced by stagnation.

Finally, because most maturing small-stem stands have only moderate to low biological potential to respond to silvicultural treatments, thinning solely from the standpoint of increasing merchantable yield is generally not justified. However, Hutchison (1964) notes that it is impossible to separate the timber-growing and multiple-use considerations in lodgepole pine management. He contends that the explosive buildup in insect and fire potential in many unmanaged stands may result in higher economic costs in the long run for no management than for management. Furthermore, increased nontimber benefits resulting from silvicultural treatment of small-stem stands may well outweigh any increase in merchantable volume increment. In fact, timber harvest may be the most useful tool available to managers for achieving nontimber objectives related to wildlife habitat; recreational opportunities; watershed management; and insect, disease, and fire control (Barger and Fiedler 1982).

Two factors, wildfire and cone serotiny, are primarily responsible for the overstocked conditions in small-stem stands. Because cone serotiny is an adaptation to fire (Perry and Lotan 1979), these factors usually work in combination. Development and recycling of a vast majority of small-stem stands fit the following general pattern: Dense lodgepole pine stands develop and mature. As these stands start to break up, fuels accumulate and fire hazard builds to an explosive potential. Wildfire inevitably follows, and tremendous numbers of seeds--equivalent to several or many years' seed production--are subsequently released from serotinous cones. Dispersed seeds fall on highly receptive seedbeds and encounter little or no vegetative competition. Dense young stands regenerate, and the cycle repeats.

Regenerated stands vary widely in density due to differences in fire intensity, seedbed condition, age and density of the previous stand, and available seed supply. However, Smithers (1961) found that dense stands remain dense, regardless of site quality. He also reported that overstocked lodgepole pine do not express dominance well. Thus, overstocked stands mature with little crown differentiation and only minor suppression mortality until late in the life of the stand.

Successionally, most small-stem stands can best be described as playing a "persistent" role. Pfister and Daubenmire (1975) assign this successional role in situations where lodgepole pine is the dominant cover type in even-aged stands, with little evidence of replacement by shade-tolerant species. The success of this highly intolerant, pioneer species in capturing and maintaining site occupancy can be attributed to three factors:

1. Repeated fires may have eliminated seed sources of other species.

2. Lodgepole pine stands may be too dense to allow other species to regenerate.

3. Light surface fires may selectively remove seedlings of less fire-resistant species such as Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.).

However, Pfister and Daubenmire (1975) report that current knowledge does not allow confident projection of "persistent" lodgepole pine stands to eventual climax status.

The rotation age of lodgepole pine stands varies greatly over the species' range. Stands in northeastern Washington and northern Idaho start breaking up at ages of 80 to 100 years (Lotan and Perry 1983). Stands in northwestern Montana are similarly short lived. Nevertheless, stands at higher elevations in Montana may last several hundred years (Tackle 1961), and stands over 300 years old are common in southwestern Montana and northwestern Wyoming (Lotan and Perry 1983).

The lengthy biological rotation of lodgepole pine stands over most of the species' range is fortunate from the standpoint of utilization. This attribute of "storing well on the stump" provides additional time to develop financially feasible systems of recovery and utilization.

More than 20 years ago, Hutchison (1964) outlined two possible scenarios for utilization of the lodgepole pine resource. The first scenario proposed that the lodgepole pine type was in fact excess timberland, unlikely to be needed to meet timber requirements in the foreseeable future. The second suggested that this species had not yet come into its own, and that time and national need would remove the marketing handicaps that had long plagued development and utilization of this resource. The current situation is probably best described as an extended transition period between the two scenarios, but it more closely fits the second.

Significant gains made over the last two decades suggest that the problem of utilization and management of lodgepole pine can gradually be overcome through continued improvements in inventory, access, harvesting, processing, product development, and marketing. Increased utilization of this species resulting from progress on any or all of these fronts would not only contribute to the nation's long-term timber supply, but would also increase the nontimber benefits from this

extensive, valuable, and distinctive Rocky Mountain forest resource.

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RESOURCE MANAGEMENT ISSUES AND DIRECTION FOR LODGEPOLE PINE FOREST LANDS--NORTHERN ROCKY MOUNTAINS

Alfred S. Gilbert

ABSTRACT: Lodgepole pine occurs on a wide variety of sites and has a number of advantages including prolific and consistent seed production, rapid juvenile growth, and wood with characteristics that are desirable for human uses. On the negative side, it frequently occurs in dense stands, is short lived and subject to catastrophic losses, and has a low stumpage value. Lodgepole pine has long been recognized for its usefulness in producing various timber products. At the same time lodgepole pine sites provide cover and forage for wildlife, feed for livestock, cover for watersheds, pattern and color to scenic vistas, shade for campgrounds, and frequently pay for the roads that help us see these things. Lodgepole pine has different values to different people. In many cases these values can be conflicting. Our challenge is to manage these lands so that they best produce what people want from them.

LODGEPOLE PINE--THE SPECIES

Lodgepole pine has a number of advantages in comparison to other trees in the Western United States. It has very wide distribution and is able to exist on a wide variety of sites. Second, it produces seed at a very early age and on a relatively continuous basis. It also has the ability, through serotinous cones in many of the stands, to store tremendous quantities of viable seed on the site. A third advantage is that it appears to express dominance at a relatively early age, thus providing opportunities to thin young stands and possibly achieve genetic gains. Fourth, the wood has characteristics that many people like. You know what I mean if you have ever had the pleasure of quickly driving a nail into a lodgepole pine stud versus bending the nail or splitting a corner off one of our more valuable larch or Douglas-fir studs. From the standpoint of this workshop, perhaps one of the chief advantages is that this is one of the few western softwoods that people are willing to buy in significant amounts when it comes in small sizes.

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As with any good thing, there are disadvantages too. The advantage of prolific seed production can result in the disadvantage of overstocked stands. This results in a decrease in the various benefits that might come from the stand or an increase in the cost to get it to the condition we would like it to be in. A major disadvantage is that the species is relatively short lived and is subject to catastrophic damage by fire, mountain pine beetles, and wind. Another disadvantage is that the species just does not grow as big as some of its neighbors or produce as much volume per acre. Therefore, it tends to have low stumpage values.

RELATIONSHIP TO VARIOUS RESOURCES

Lodgepole pine forests afford a full spectrum of potential resources and uses, including wood products, recreation opportunities, wildlife habitat, water, and forage. Management is rarely directed toward a single resource or use, but rather toward an integrated mix of resources. Characteristics of lodgepole pine as related to various resources are consequently of major importance in defining management issues and direction.

Timber

Lodgepole pine historically has been used for firewood, houselogs, and posts and poles. In southwestern Montana, significant acreages of lodgepole pine were harvested to produce mine timbers and fuel for the smelters. Throughout Montana, many lodgepole pines were converted to railroad ties. In the mid-1950's, large quantities of lodgepole were cut into pulpwood bolts and shipped back to Minnesota for processing. However, technology to efficiently handle small-diameter stems did not come about until the early 1960's so that significant quantities could be milled into studs and lumber.

Today's uses of lodgepole pine are lumber, houselogs, posts and poles, firewood, and until recently, railroad ties. Mining activities have not maintained their share of the market, but some other uses such as power poles and core stock for plywood have developed. The share of the market that lodgepole is supplying is increasing (12 percent in 1969 to 25 percent in 1981), and the amount of lodgepole available is being better utilized (about 20 percent of annual growth in the 1950's compared to about 65 percent in 1984). Lodgepole certainly is not the weed

species that it was perceived to be just a few decades ago.

Looking into the future and considering lodgepole pine's assets, it appears that the fiber market could be an area of large opportunity.

Wildlife

Just by virtue of the extensive areas of land that lodgepole occupies, it has a significant effect upon wildlife.

Because of the seral role that lodgepole occupies in most cases, it is usually not associated with the old-growth-related wildlife species. However, it does play a role in providing consistent supplies of seed for squirrels (a favored prey of the marten), and the dead and down remains of lodgepole are often important in providing niches for ants, which are important food sources for piliated woodpeckers.

The cover and forage associated with lodgepole pine forests provide homes to large numbers of deer and elk. The elk are more efficient in their use of this environment because of their willingness to eat grasses and shrubs in the meadows; the deer tend to prefer forbs in either the forested or meadow environment. Because of this, there may be more potential to improve conditions for deer through the increased number of forbs produced when the forested community is disturbed. The benefits are often considered to be short lived (about 20 years), but can be extended through thinning.

Livestock

Lodgepole pine is generally considered to have limited value to livestock. This is due both to the quantity and quality of forage produced. Studies indicate that disturbance (clearcutting) does increase forage production for about a 20-year period and that the effect peaks about 11 years after the disturbance. The benefits can be enhanced and extended through seeding of early season grasses and by thinning.

Many concerns have been expressed about the impacts of cattle grazing on tree regeneration. It is generally acknowledged that the effect is due to trampling rather than grazing damage. Damage can be extensive in areas that are overgrazed. It appears that compatibility can be achieved with proper livestock management.

Watershed

The extensive stands of lodgepole pine provide protection to a large number of watersheds. They are important in providing us with cool water of high quality. However, as mentioned earlier, these stands are subject to catastrophic losses. Vegetative manipulation on those scales can be quite damaging to watersheds on at least a short-term basis. Planned manipulation of the vegetation has potential to provide additional amounts of water downstream and to affect the timing of runoff to some extent. It might very well be that in the future increased water is the most valuable of the products that is realized from our manipulation efforts.

Recreation

Stands of lodgepole pine provide patterns and color to many of our scenic vistas. They are also where a number of our developed recreation sites are located. The harvest of timber (including lodgepole) has paid for most of the roads that provide us with motorized recreation and created favorable sites for berry production and winter sports play areas. Our long-range management plans must consider user safety and convenience in being able to use these lands.

MANAGING LODGEPOLE PINE FORESTS TO MEET HUMAN DESIRES

The point I have been trying to make is that the products lodgepole pine forests produce are not limited to boards, or posts, or firewood. They include a wide number of things that various segments of our society desire.

Lodgepole pine has different values to different people. To some, the highest value is the potential for a wood product; to others, it is an opportunity to manipulate to improve conditions for something else; and to still others, it is something that best serves their purpose by remaining totally undisturbed in a "natural" state.

In many cases, these values are desired on the same piece of land. Resolving the conflict is one of our major management issues. It is not a situation of growing a product and then offering it to the highest bidder. Although "market value" might help to resolve some of the conflicts, many are expressed in qualitative terms. These are difficult to compare against the other values. In some cases, the value might even be expressed as a constraint against another use.

Sales Below Cost

An example of the latter case is the issue of timber sales "below cost."

Lodgepole pine is an aggressive species that can grow on harsh sites better than many of its associates. Because of this, many lodgepole stands occupy sites that are relatively difficult to develop access to. Many of the higher elevation areas are in esthetically sensitive areas and require special layout techniques. Especially in the eastern part of our area, many of the stands are interspersed with nonforested areas. These sites have other resource values, but do not contribute toward the cost of developing roads into the area. As in the case of the visually sensitive areas, particular care must be taken in laying out a timber sale.

In some cases, other resource values such as big game, threatened or endangered species, old-growth dependent species, and water temperature might require certain management constraints to optimize the desired conditions.

Finally, lodgepole pine comes to us in small packages and is relatively expensive to harvest and manufacture.

All of these things add up to quite a bit of expense. When other factors are added in, such as low competition in some areas, extended rotations, or infrequent reentry periods, then the initial entry might not cover all of its costs.

In determining whether or not this situation is acceptable, we must consider whether the costs of the timber sale are appropriate over time, what the costs would have been by implementing some alternative treatment method, and what the costs would be of foregoing the treatment. If the sale cannot meet those tests, then it probably deserves the bad name that it has received.

Lodgepole is Short Lived

Many people who favor nonwood uses for our lodgepole stands strongly defend leaving the stand "natural" or "keeping it just like it is." I submit that this approach ignores one of the realities of lodgepole pine, which is that it is a relatively short-lived species that is very prone to catastrophic occurrences.

Extensive areas, primarily in the Kootenai, Flathead, Beaverhead, and Gallatin National Forests and Glacier and Yellowstone National Parks, have recently experienced mountain pine beetle epidemics. At first, many people's reactions were displeasure that we had not done something to keep their forests from becoming red and subjecting them to the risk of extensive wildfire. Now that the forests are a grayish-green color, these people are again asking that the forest be kept the way it is. I suspect that not until extensive quantities of these dead trees start to come down and people have trouble making their way through the woods, will they again question leaving it "natural."

In the past few years, some of our large wildfires have reminded us that even though we have much better access to the areas, and have gained tremendous capability in personnel, equipment, and techniques, we still are not able to keep the vegetative manipulation within the desired scope. We have unrealistically constrained timber harvesting in areas where the end result was loss of timber to insects or fire--not maintenance of a desirable stand.

MANAGING WITH CONFIDENCE

What does all of this discussion lead up to? Should we duck into our holes and wait for the good old days to return? I submit that we cannot and should not do this. As with the case of the big fish and the easy elk, it just is not likely that the good old days will ever return; in fact, they may never have existed. Each era seems to have its set of problems (no markets, no access, and so forth).

First, we have acquired a tremendous amount of knowledge about the characteristics of lodgepole pine and what it takes to manage it. Second, we have acquired the technology and equipment to be able to manipulate the vegetation and to produce usable products in a cost-efficient manner. Third, we are becoming more aware of economics as a factor in our management decisions. Unfortunately, it is no longer enough to just "do good in the woods." Some of our publics are just not satisfied with that. For a variety of reasons, they expect us to be "more complete managers."

A discussion of acceptable forestry practices on private nonindustrial lands indicates that landowners frequently have two basic guidelines: (1) The treatments prescribed must look good at the time they are completed, and (2) they must not cost any money. The landowners often do not mind accepting a lower profit, they just are not willing to pay something out of their pocket. Long-term forest management is usually a secondary objective at best.

The public forester is also subjected to a lot of pressure to select management options that make it look good or leave it natural. Do we tend to bend and flow with the desires that are currently popular? I submit that all of us have the responsibility to inform our publics of what the realistic range of alternatives and possible effects are. Once these are understood, we should then follow their desires within the constraints of the resource. I hope that we are never accused of being like an electrician who provides a cheap, good-looking wiring job, but the client's house burns down because the electrician did not explain the risks of overloading the circuits.

CONCLUSIONS

We have a species to work with that provides a lot of opportunities and a lot of challenges. Lodgepole pine is intricately linked with a variety of resources and provides us with many products. We must use our professional expertise to describe what the requirements and opportunities are, work with our publics to determine what they desire, and find or develop the equipment and technology to be able to produce it in a cost-effective manner.

I am confident that we are at the stage where we can do these things.

RESOURCE MANAGEMENT ISSUES AND DIRECTION FOR LODGEPOLE PINE FOREST LANDS--INTERMOUNTAIN REGION

Orville E. Engelby

ABSTRACT: Summarizes the management issues and direction currently being developed in the Forest Service Intermountain Region for lodgepole pine forest lands through Land Management Planning efforts. The political process and nature of the "publics" involved have resulted in an apparent polarization of special interest groups. Completion of Land Management Plans will not reconcile all the conflicting interests. Proposed activities in roadless areas not designated wilderness will continue to be an issue. Inventories show that the majority of the commercial lodgepole pine is in the over-80-year age classes.

INTRODUCTION

Management of millions of acres of lodgepole pine in the Intermountain Region of the Forest Service, U.S. Department of Agriculture, is affected by many factors that can be placed into four broad categories:

1. The political process
2. Land management planning or resource allocation
3. Current economic situation
4. Biological factors.

The political process is listed first because it is the arena within which all issues must be addressed. The last two, the economic situation and biological factors, are more critical to lodgepole pine management than to most other timber species because of the small size and low value of the trees, and the nature or condition of our stands.

This paper discusses the broad categories in the order shown. Although many situations appear to be obstacles to sound forest management, generally our expertise has improved over the years and the outlook for better utilization of lodgepole pine in the future is good.

Paper presented at Workshop on Management of Small-Stem Stands of Lodgepole Pine, Fairmont Hot Springs, MT, June 30-July 2, 1986.

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THE POLITICAL PROCESS

Just as we are in the United States, foresters in other parts of the World are experiencing some difficulty practicing their profession in their respective political arenas. The New Zealand Forest Service was started in 1920 to avoid a predicted domestic wood shortage. Foresters have long heard and read about their great successes with radiata pine. New Zealand is currently exporting 20 percent of its allowable annual cut and would be capable of exporting one-half by 2000. The New Zealand Forest Service was a proud, professional, and successful outfit. It has essentially been disbanded. The radiata pine lands (about 20 percent of forested land) have been put under the Department of Agriculture for management and the native forests (80 percent) have been transferred to the Park Service. Among the reasons given is: "The people did not trust them with all the native forests." In spite of the great success of the New Zealand Forest Service in doing what it was formed to do, its management job has been taken away.

As of last summer Sweden had a complete moratorium on use of herbicides in forestry.

If there is a lesson here, and I suspect there is, it is that we must work within the political system and maintain the public's trust. We have long-standing direction like "the greatest good for the greatest number in the long run." We talk about "the public," and we invite "public involvement" to help us make management decisions. In fact, we are directed by law to have public involvement. The problem is getting and then evaluating the public comments. We worry about the "silent majority" and struggle with what is the overall "public interest." Forest Service Chief Max Peterson recently stated: "One of my failures is that I had hoped to decrease the polarization of the groups that use the National Forests, and that has not been accomplished very well."

Behan (1979) gives us some real food for thought concerning public involvement. He points out the writers of the Constitution were afraid of "majority rule" and designed a fragmented system of political power that prevents mobilizing a majority. Parties emerged to handle elections, and a system of interest group interaction emerged to handle policy formation. He goes on to state that the majority are silent for several reasons: They do not know about the issue at hand; they do not care about the issue at hand; they may know and care about the issue at hand,

but defer to others its resolution; or they may not be affected by the issue at hand.

By virtue of our constitutionally designed system, the knowledgeable, concerned, and affected people in a given issue will appear as conflicting minorities. We should not be surprised or dismayed when all we get from public involvement appears to be conflicting special interest groups.

As foresters, one other point complicates our ability to communicate effectively with "the public." That is the timeframes we think in and talk about. Not only are we a Nation composed of special interest groups, we are conditioned to instant results. Our TV's come on instantly, car radios are wired to the ignition, and we cook with microwaves. Americans are interested in how things affect us right now--not in the long run. We are working with a public that is conditioned to expect instant results, and as foresters we blissfully talk about 100-year-plus rotations.

LAND MANAGEMENT PLANNING

As a result of increasing concerns over management practices in the National Forests (Monongahela, Bitterroot, Wyoming Report, and others), Congress passed the National Forest Management Act of 1976 (NFMA). This act, among other things, mandated that the National Forests complete resource allocation plans, known as Land Management Plans (LMP). We have devoted tremendous amounts of time, energy, and funds to complete these plans. At the same time, we also have the National Environmental Policy Act (NEPA), RARE I (we did not know it was RARE I at the time), RARE II, Ninth Circuit Court Decision, and numerous State wilderness acts passed and not passed, just to name a few of the legislative mandates the National Forest System has been given.

As Forest Plans are completed (with public involvement) and are sent out for public review and comment, the confrontation of conflicting special interest groups seems to be intensified. It has been described as "Utilitarians vs. Naturalists" and "Developers vs. Conservationists," and "the Big Grab for Wild Lands" by U.S. News and World Report (1986). Only time will tell how successful the legislative mandate of NFMA and our Agency efforts to resolve conflicting land use allocations will be. Concerns at the time of NFMA focused on size of clearcuts, lack of regeneration, and appearance of areas following clearcutting. Now they focus on extension of road systems and size of harvesting programs--no longer quality of the work but quantity. This is much more difficult to address.

In the Intermountain Region, the States of Wyoming and Utah both have Wilderness Acts for National Forest System lands. In both States, activities proposed in roadless areas not designated wilderness or for further study are currently under appeal. At the dedication of the Utah wilderness areas with all the appropriate representatives present (agency, timber, grazing, minerals, and wilderness), the Utah Wilderness Society Representative stated: "This is just the beginning."

I believe the cards are on the table, and given our constitution and political processes, and the interests involved, we would be naive to assume that land use plans will make our life simpler. Activities proposed will continue to be appealed by the party that feels wronged. Mark Rey of the National Forest Products Association stated: "The debate will not completely end until the last roadless forest tract is designated for logging or preservation as wilderness."

CURRENT ECONOMIC SITUATION

Current economic conditions also seriously affect lodgepole pine resource management in the Intermountain Region. The introduction to silviculture in a popular textbook (Daniel and others 1979) flatly states: "Forestry must be sound both biologically and economically if it is to really work." Then after covering the effect of "over-elaborate management" on private forestry enterprises, the authors go on to state:

> But even in public forestry where strict dollars-and-cents accounting for all tangible and intangible "goods and services" produced by the forest is neither possible nor desirable, there must be some balance in the long run between the cost of forestry and its returns.

This economic approach to public forestry has gotten somewhat more complicated with the current national debt and the emphasis on cash flow.

President Reagan has stated: "Those who receive special benefits and services from the Federal Government should be the ones to bear the costs of those services--not the general taxpayer." At a February 1986 conference on below-cost sales, then Assistant Secretary of Agriculture Peter Myers said: "The real issue is not costs versus revenues, but cost versus public benefits." All these tenets are interesting to contemplate in the current climate of:

1. Below-cost timber sales
2. Cash flow in government
3. Gramm-Rudman-Hollings amendment
4. Multiple-use management of public lands.

Much has been said and written about Forest Service below-cost sales. To me, the debate has produced much more smoke than illumination. Long-term investments in multiple-use forestry can be very difficult to justify when the emphasis is on annual cash flow. Given what I have stated about our political processes and our Forest Service efforts in LMP to reconcile allocation for uses, I submit that the real issue is not below-cost sales at all, but allocation of National Forest

System lands for certain uses. It's not the fact that there are below-cost sales, it's how they affect a special interest right now. Many enjoy the below-cost recreation, hunting, and fishing that the National Forests provide. Last year, the National Forest recreation program cost $100 million and returned $30 million. Sounds to me like a below-cost program. How fair is it for the general taxpayer to pay for the recreation of those who utilize the National Forests for their recreation? How fair or logical is it to judge the timber program by one set of principles and apply another to the recreation program?

The basic issue is not below-cost sales or cash flow. It is how many million acres will be designated and managed for wilderness, and how many will be managed for other uses, such as timber management. Another interesting statistic always comes to mind here: "Only 6 percent of all National Forest recreation occurs in wilderness." This reaffirms what I said earlier about our political system. By its very design and nature it does not concern itself with the majority, but rather the interested and affected conflicting minorities.

BIOLOGICAL FACTORS

In the Intermountain Region, we have a substantial acreage of commercial lodgepole pine type. To get a clear picture of what the resource looks like, I have graphically displayed the commercial lodgepole pine type acres by age groups for four of our National Forests--the Ashley, Wasatch-Cache, Bridger-Teton, and Targhee--with sizable acreages of lodgepole pine.

Because all the inventories are at least a decade old, I added a decade to each age group. I then created the 1- to 10-year age group from each Forest's Silviculture Accomplishment Reports (FY 1976 to 1985). Therefore, the solid bar, 1- to 10-year age group, should be subtracted from the crosshatched bars, but I do not have a good way to display this. For the purpose of visualizing the age class structure of these Forests, it is sufficient to know that the created 1- to 10-year age group had to come out of the total type (crosshatched bars), and probably primarily from the older age groups.

Most of the 27,000 acres of lodgepole over 211 years old in the Ashley National Forest (fig. 1) is at high elevations on the north slope of the Uinta Mountains, where insect and fire intervals are less frequent than at lower elevations. We are currently experiencing a mountain pine beetle epidemic in the Ashley National Forest, and the Forest Service is getting some accelerated harvest under way. The 1984 Insect and Disease Condition Report estimated 2.9 million trees killed by mountain pine beetle in this Forest.

In the Wasatch-Cache National Forest (fig. 2) mountain pine beetle infestations are developing or spreading from the east, in a pattern similar to those in the Ashley National Forest. Most of

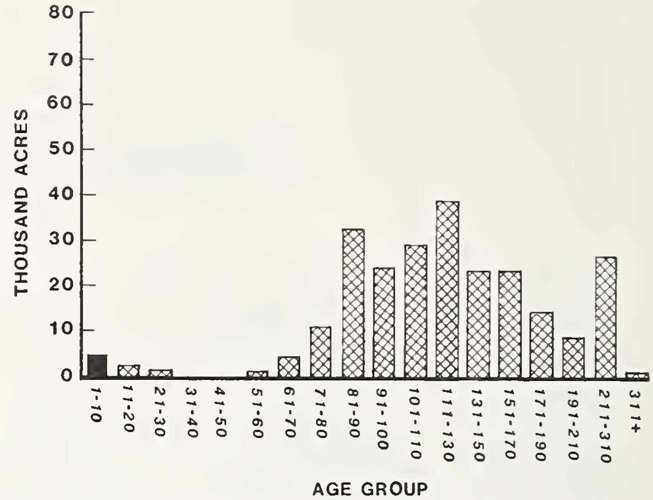

Figure 1--Commercial lodgepole pine acres by age classes--Ashley National Forest. Crosshatched bars represent 240,263 total acres. Eight percent of the lodgepole pine is less than 80 years old, 31 percent is less than 100, and 43 percent is less than 110. About 27,000 acres is over 211 years old.

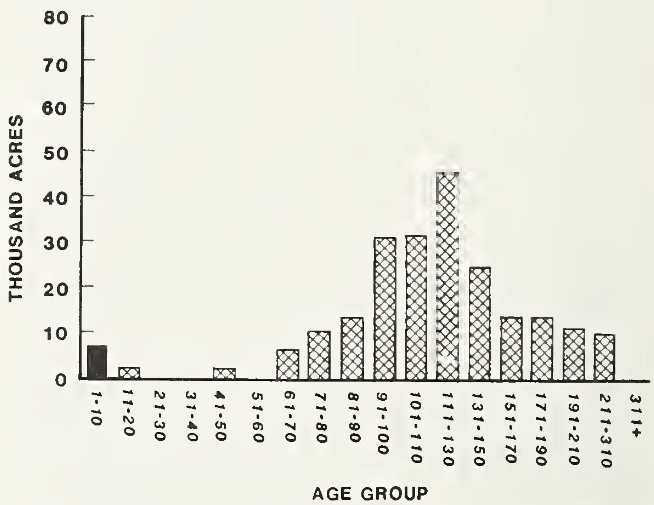

Figure 2-- Commercial lodgepole pine acres by age classes--Wasatch-Cache National Forest. Crosshatched bars represent 212,131 total acres. Sixteen percent of the lodgepole is less than 90 years old and 45 percent is less than 110. Some 9,000 acres is over 211 years old.

the lodgepole in this Forest is west of the Ashley on the north slope of the Uinta Mountains. The 1984 Insect and Disease Condition Report estimated 325,000 trees killed by mountain pine beetle in this Forest.

An interesting note in relation to the 71- to 110-year age groups in the Bridger-Teton National

Forest (fig. 3) was reported in the Bridger-Teton Activity Review in 1985:

> Fire scar evidence and historical accounts indicate that very large fires took place in the early 1870's, 1879, and 1880. The year 1879 was particularly severe. Much of Jackson Hole and large areas in the Teton Mountains, Island Park, and Yellowstone National Park burned. (Remarks by George Gruell, activity review participant).

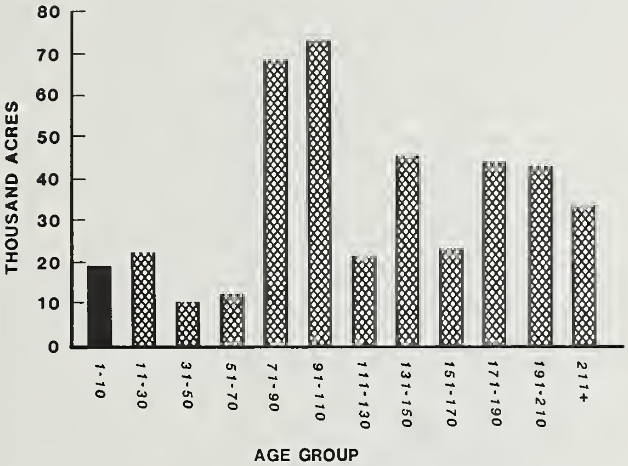

Figure 3--Commercial lodgepole pine acres by age classes--Bridger-Teton National Forest. Crosshatched bars represent 394,635 acres. Twenty-nine percent of the lodgepole is less than 90 years old and 52 percent is less than 130. Some 33,452 acres is over 211 years old.

The Targhee National Forest (fig. 4) shows some interesting differences. The data are from the same sources and displayed in the same manner; however, the inventory portion (the crosshatched bars) should be considered as before the full-scale mountain pine beetle epidemic and accelerated salvage harvesting. The solid bar represents an accelerated reforestation program to keep pace with the salvage harvesting. The 77,000 acres of created 1- to 10-year age group is significant and must be subtracted, mentally at least, from the 403,000 acres represented by the crosshatched age groups.

The Targhee does not have the high-elevation lodgepole type as do the Ashley and Wasatch-Cache National Forests, and the insect and fire frequency is less. Two more decades like the last one and we will have this Forest pretty well reforested. Our direction now is to schedule the Timber Stand Improvement (TSI) program to regulate the harvest in a more orderly manner--move some stands toward their harvest diameter faster (sudden sawlog prescriptions) and hold others back somewhat to regulate and space out future harvest.

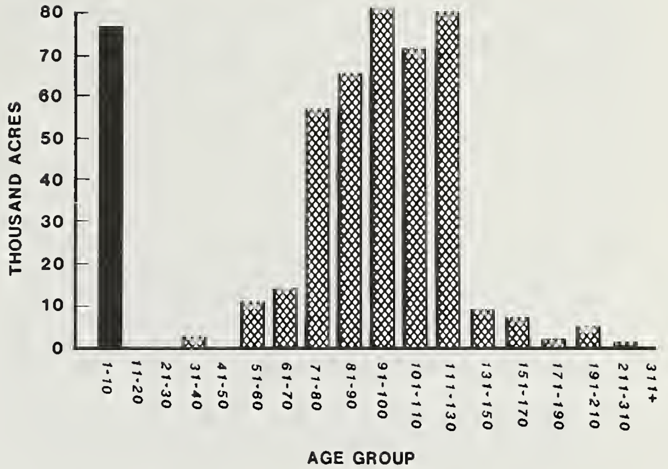

Figure 4--Commercial lodgepole pine acres by age classes--Targhee National Forest. About 77,000 acres is in the created 1- to 10-year age class. Age distribution before the mountain pine beetle epidemic was 6 percent less than 60 years old, 88 percent between 60 and 120, and less than 2 percent over 160.

From these displays of the lodgepole pine resource in four National Forests, we begin to get the picture on age class distribution. Knowing what we know about the silvics of lodgepole pine and recent historical experience in the Targhee National Forest, we can speculate on the future of lodgepole pine in these Forests.

It is apparent in the Intermountain Region that we have substantial acreages of older age class lodgepole pine. It also seems apparent that lodgepole pine (the majority species) has and probably will in the future recycle quite rapidly. The biological factors affecting lodgepole pine forests have been studied and evaluated, and alternatives for the future described and evaluated with at least some degree of scientific soundness. The biological factors are probably the easiest of all to deal with. The problem is dealing with the biology of the species on public lands in the current political arena and current economic situation.

SUMMARY

I was asked to address the "Resource Management Issues and Direction for Lodgepole Pine Forest Lands in the Intermountain Region." Most of my presentation has been on issues. The management direction will come from the LMP's. Project direction is contained in stand- and site-specific prescriptions prepared by certified silviculturists for each timber sale, timber stand improvement, or reforestation proposal. We use the full range of silvicultural treatments from clearcutting to partial cutting and density management. By looking at the issues at this time I may sound pessimistic. I do not intend to

be; we have well-trained silviculturists preparing prescriptions at the sites. The information presented at this symposium will undoubtedly help them greatly with regard to the engineering, utilization, and economic aspects of the lodgepole pine areas we can treat and manage.

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SILVICULTURAL OPTIONS FOR SMALL-STEM LODGEPOLE PINE

Wyman C. Schmidt

ABSTRACT: Lodgepole pine's reproduction habits have perpetuated the species over a wide range of geographic, physiographic, and ecological conditions. However, its propensity to reproduce in abundance leads to severe overstocking problems that are a real challenge to land managers. Silvicultural options for dealing with overstocked lodgepole pine stands are limited more by tradition and economics than by biology. The options include: (1) Do nothing, (2) harvest and start over, (3) intermediate cutting, (4) fertilize, (5) destroy with fire or mechanical means and start over, and (6) combinations of these. Each option has advantages and disadvantages. These vary under the different combinations of stand density, structure, and composition; site quality; age; and social and economic factors that bear on management decisions. Up to now, the most commonly used option is to do nothing, but as demands increase for the resources these stands have to offer, we can expect a shift toward some of the active management options.

INTRODUCTION

Lodgepole pine is often referred to as the "Cinderella" species of the West. This analogy holds very true for many characteristics of this species, particularly when we think of how it was long ignored but is now being recognized and is coming into its own. However, lodgepole pine may not be such a Cinderella after all. Some things have been ignored in accepting the analogy. The innocent lost slipper and the coy wait for Prince Charming may have been a ruse. The facts are, our Cinderella species is actually a seductress that spends her time from youth until old age reproducing, and reproducing, and reproducing.

She pays the price, though. Eventually, her many offspring compete so vigorously for their place in the sun that many die long before youth is past, many become stunted and live well below their potential, and many stay uniformly small. Only a few break out of the mold and excel in their growth and stature.

Paper presented at Workshop on Management of Small-Stem Stands of Lodgepole Pine, Fairmont Hot Springs, MT, June 30-July 2, 1986.

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That's not a totally happy ending to a tale that normally has Cinderella living happily ever after. But like many other tales it's closer to fact than fiction. What kind of forest problems has this Cinderella of the West given us and what are our silvicultural options for dealing with them? That is the subject of this paper.

THE SCENARIO

Lodgepole pine extends over 60 million acres in the United States and Canada (Wheeler and Critchfield 1985). Most lodgepole pine stands are overstocked, and overstocking has long been considered one of the most vexing problems in managing the species (Alexander 1974; Cole 1975). Densities exceeding 100,000 trees per acre have been observed in young stands and although suppression rapidly reduces their numbers, far too many survive, drastically reducing growth of individuals (Lotan and Perry 1983). In fact, extreme overstocking often results in stagnation--the near complete cessation of height and diameter growth. Bassman's (1985) work with height and live-crown ratios of 20-year-old lodgepole pine stands suggests that stagnation may occur in stands with 10,000 to 20,000 trees per acre.

Lodgepole pine grows under a wide range of geographic, ecologic, edaphic, and physiographic conditions. These factors comprise what we call "site" and provide the first big clues to what must be considered in any silvicultural prescription (Schmidt and Alexander 1985). Site factors combined with damaging agents such as fire, insects, snow, wind, heat, and disease profoundly influence the establishment, stand development, and mortality of lodgepole pine. We must also consider the inherent characteristics of the species such as seed production from both serotinous and nonserotinous cones, seed dispersal, seedling germination and survival characteristics, and a host of other attributes. This series of factors makes up a complex matrix that must be considered in making silvicultural decisions in these forests.

We must look for ways to simplify the process for making logical silvicultural decisions in lodgepole pine forests. In most cases, these forests can be categorized into different classes of age, density, stand structure, composition, and site quality. The variance of each of these provides a broad spectrum of conditions that need to be evaluated before making site-specific silvicultural decisions to meet manage-

ment objectives. I hope this discussion of options will help answer one of the most common questions asked by managers of overstocked lodgepole pine stands--"I inherited these stands, now what can I do with them?"

SILVICULTURAL OPTIONS

At the outset of the research being addressed at this workshop, an effort was made to consider a broad range of utilization and silvicultural research objectives for overstocked lodgepole pine. As described in more detail in other papers given at this workshop, treatments were selected to most closely meet the composite short- and long-term objectives, design criteria, and budget constraints. This boiled down to two levels of intermediate cutting, a do-nothing control, and some clearcuts (harvest and start over) on study areas mostly in Montana, with some in Utah. I want to point out that the terms "thinning" and "intermediate cutting" are often used synonymously, but "intermediate cutting" is used in this paper because of the broad objectives of the studies being reported at this workshop. These treatments cover only some of the viable silviculture and utilization options for immature but overstocked lodgepole pine forests. Utilization options are covered in other workshop papers.

Before the other speakers discuss the results of the studies of the selected treatments, let's examine a somewhat broader range of silvicultural options that might be employed for various stand-site-age condition combinations (fig. 1, 2, 3, 4). Finding the situations where these options can be logically employed is one of the objectives of this workshop and also that of the long-term phase of this study as well as other studies in the lodgepole pine type. Knowing when and how to employ these options is a management decision based largely on biological, social, and economic goals for a given set of forest conditions. The options and their advantages and disadvantages are:

DO NOTHING

Some advantages	Some disadvantages
No investment cost	Potentially productive land produces far less utilizable wood products than it could
May provide some resource values, for example, watershed, wildlife habitat, and esthetics	Foregoes most biological and social resource values
Utilization standards and opportunities may change enough to make these stands economically viable at a later date	Source of insect, disease, and fire problems

Figure 1--Intermediate harvest cuttings can accelerate growth and be a viable option in vigorous lodgepole pine forests that have not been too severely overstocked. Conversely, a "do nothing" policy may best meet overall management objectives on some sites.

Figure 2--Harvesting and starting over with young manageable stands may well be the best silvicultural option in many overstocked or diseased lodgepole pine forests.

Figure 3--Intermediate harvest cuttings can enhance a broad spectrum of resource values in addition to increasing growth of trees to be featured in management.

Figure 4--Fire can play an important role in disposing of slash and preparing the site for regeneration after harvesting or it can be used to convert hopelessly overstocked or diseased lodgepole pine forests to younger manageable stands.

HARVEST AND START OVER

Some advantages	Some disadvantages
Can provide upfront revenue	May have to be done at a deficit
Utilizes some of the resource	May produce little utilizable wood
Provides the opportunity to start over with a young manageable forest	May be difficult to implement in heavily cutover areas because of hydrologic, cover, and other limits
Reduces insect and disease potential	May incur regeneration costs
Creates diverse habitat for wildlife and improves management options for other resources	Markets cannot absorb large increases in supply

INTERMEDIATE CUTTING

Some advantages	Some disadvantages
Utilizes some of the wood resource	May incur net costs
May produce net revenue	Wind and snow damage may occur in reserve stand
Can reduce insect and disease problems	Mechanical damage during thinning operation may result in entrance for disease
Can increase resource values in wildlife habitat, water, and esthetics	Slash can inhibit wildlife movement
Can provide part of an overall strategy to establish age diversity in the type	If improperly done, may increase disease and insect problems
Increases growth of individual trees	In many situations requires expensive hand labor instead of less costly mechanical methods

FERTILIZE

Some advantages	Some disadvantages
Can increase growth of reserve trees in thinned stands	Generally ineffective in unthinned stands
Can enhance understory forage	Incurs costs well before results can be realized
May increase resistance to insects under some site and type of fertilizer combinations	Growth response is usually short-lived
	May attract more insect and animal

damage under some site and type of fertilizer combinations

DESTROY - PRESCRIBED FIRE

Some advantages	Some disadvantages
Low-cost method of stand conversion	An upfront expense
Can regenerate new stand with manageable composition and density	With poor fire regulation, may just perpetuate the problem by producing another overstocked stand, or it may require the expense of planting or seeding if all seed is burned under the wrong prescription
Closely resembles "nature's method"	Very limited season for prescribed burning on most lodgepole pine sites
By regulating fire intensity, may be able to reduce seed supply and subsequent overstocking	Requires good fire management skills
Usually leaves some shade to enhance seedling survival	If burned too hot on some sites, nutrient capitals, particularly of nitrogen, can be depleted
Reduces insect and disease problems	May have a temporary loss in esthetic values
Usually increases other resource values such as forage	
Can increase availability of nutrients	

DESTROY - MECHANICAL

Some advantages	Some disadvantages
Can regenerate new stand with manageable composition and density	An upfront cost
Have more seasonal latitude in doing the work than with fire	Severely impacts visual quality
Usually increases understory forage	Will usually result in far too many serotinous cones on the ground and as a result too many seedlings
Reduces insect and disease problems	Regulating regeneration composition and density is difficult
	Soil compaction can be a problem on some sites
	Can restrict wildlife movements

COMBINATIONS

Some advantages	Some disadvantages
May be very effective, for example, a combination of thinning and fertilizing or clearcutting to a diameter limit and burning	Increases upfront costs
May be the only feasible solution	May require knowledge and skills not yet available

SOME CONCLUSIONS

With the exception of doing nothing, the options just outlined manipulate stands to meet resource objectives and reduce insect and disease problems. Doing nothing may also meet some objectives, but no manipulations are involved. For every treatment selected, there will be advantages and disadvantages. Those listed here are certainly not exhaustive, but they do provide some idea of the give and take involved with any treatment selected to solve overstocking problems in lodgepole pine stands.

One might argue the case for any of the treatments described here or, for that matter, treatments not mentioned here. What might be a suitable treatment for one site, age, density, and composition combination may be totally unsuitable for some other combination. Even if we had near homogeneous conditions over large areas (and sometimes we do), choosing one uniform treatment for the entire area is usually not a wise biological choice. With a "cornfield management" approach we could mechanize and standardize and vastly improve efficiencies in the whole tree-growing process. Unfortunately, this is not compatible with many resource management objectives. Promoting lack of diversity in size, age, structure, and distribution of stands can lead to serious insect and disease problems. It also leads to reductions in diversity of those ecological niches needed to enhance a wide variety of wildlife, water, esthetic, and other resource values.

Underlying any proposal that involves harvest and utilizing at least some of the stems in overstocked stands, there is a limit to how much the market can absorb. It may be possible to increase markets, but that is something beyond control of forest managers. Also, the current level of operation reflects some intermediate cutting and lots of "do nothing." At the current level of intermediate cutting, the overstocked stands will for the most part not contribute much to offset the projected age class gap 30 to 40 years down the road (Benson 1986). On the bright side, lodgepole pine's response to management or nonmanagement is fairly predictable. This should enhance management by reducing uncertainty and costs.

At this point in time (and I suspect most any point in time), it is hard to reliably predict what mix of timber products, associated resources, and insect and disease reduction methods will be needed in the next century when the results of most of our efforts will be realized.

Like successful investors in the stock market who rely upon diverse investments for protection against uncertainties in the long term, a mixture of silvicultural treatments in a management area is probably the best biological, economic, and social strategy for achieving the resource production needed from lodgepole pine forests in the 21st century. Workshops such as this, that meld the talents of researchers and the practical experiences of forest managers, help define the knowledge gaps and the direction needed to find the slipper that best fits our somewhat tarnished Cinderella species of the West.

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RESEARCH AND DEVELOPMENT EFFORTS IN THE UTILIZATION AND MANAGEMENT OF SMALL-STEM STANDS OF LODGEPOLE PINE

Roland L. Barger

ABSTRACT: Management of natural stands of sub-sawlog-size lodgepole pine has been repeatedly identified by forest managers as a critical problem. As a result, a major Intermountain Station research program effort during the past 5 years has been an evaluation of harvesting, utilization, and silvicultural alternatives in small-stem lodgepole pine. Field investigations have been carried out at sites representing typical natural stands of small-stem lodgepole pine 3 to 7 inches in diameter, geographically dispersed from the Wasatch-Cache to the Lewis and Clark National Forests, and representing a range of stand age from 50 to 120 years and densities of 1,000 to 6,500 green stems per acre. Typical study sites included two levels of intermediate harvest--33 percent and 66 percent basal area reduction prescriptions--and an untreated control. A few included clearcut units. Studies have included evaluations of silvicultural treatments and posttreatment stand response, harvesting practices and costs, product recovery and value, vegetative responses, and economic and management consequences of alternative practices. Results provide a basis from which managers can judge the feasibility and desirability of alternative stand treatments and utilization practices in small lodgepole pine.

INTRODUCTION

In the Interior West, small-stem stands of timber represent perhaps the single most significant opportunity for improving wood resource utilization and forest management. Two distinctly different small-stem stand conditions occur. One is typified by second-growth pole stands of ponderosa pine and Douglas-fir (and occasionally other species not inherently small stemmed when mature). The other, and by far the most extensive, condition involves stands of species that are characteristically small at maturity and may be overstocked and stagnated. The two major species almost universally considered "small timber" are lodgepole pine (fig. 1) and quaking aspen. Stands of lodgepole pine alone occupy more than 12 million acres in the inland West, following the Rocky Mountain chain from Canada south to the higher elevation lands of Utah and Colorado (Barger and Fiedler 1981).

Figure 1--Lodgepole pine, an inherently small-stemmed species, occupies more than 12 million acres in the western continental United States.

Two concerns have focused increasing attention on improving harvesting and utilization opportunities for small-stem stands. The first is concern about our continuing ability to meet national demands for wood and wood-based products, especially softwood construction materials. Predictions forecast a growing gap between supply and demand, a situation that can be partially circumvented by placing currently unmanaged timberlands under more intensive management (USDA Forest Service 1977). A second concern is the need to achieve broad resource management and protection objectives relating to

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wildlife habitat, watershed management, esthetics, and insect, disease, and fire protection. An urgent concern in lodgepole pine stands is implementation of harvesting and management strategies to reduce the probability of mountain pine beetle epidemics. Improved harvesting opportunities in small-stem stands can contribute to both immediate and long-term timber supply, while facilitating management of other resources as well.

THE RESEARCH AND DEVELOPMENT PROGRAM

In 1979, the Intermountain Research Station initiated a Research and Development Program named STEM (Systems of Timber Utilization for Environmental Management) to address barriers to utilization of small-stem and other marginal stands (Barger 1979). The Program included research in utilization, engineering, and economics in three broad problem areas:

1. Reducing impacts of road access in steep terrain.

2. Developing harvesting and utilization options for small timber and residues.

3. Integrating timber harvesting with multiple-resource management.

In addition, silvicultural and other biological researchers have collaborated with Program researchers in joint efforts to evaluate the biological implications of timber harvesting.

To identify the highest priority research needs relating to utilization of marginal timber resources, an extensive review was conducted involving forest managers across the Northern and Intermountain Regions of the Forest Service. Group discussions and responses identified 26 problem management situations that met the criterion "timbered lands upon which technical and/or economic barriers to utilization constrain the management of both timber and nontimber resources." The 26 problem situations were then assigned priorities based on such factors as urgency, extent, and researchability. In both Regions, the number one priority problem was clearly management of small, overstocked lodgepole pine stands (Barger 1980). Consequently, small-stem lodgepole pine stand management became the focus of a significant part of the Program effort for a 5-year period. It is that body of research, plus directly applicable research on other small-stem timber and areas, that is being reported in this workshop.

SMALL-STEM LODGEPOLE PINE STUDIES

Studies were planned to evaluate an array of silvicultural, harvesting, and utilization alternatives in natural stands of small lodgepole pine. Managers in both Forest Service Regions had expressed a particular interest in management options other than simply clearing by clearcutting, slashing, trampling, or burning. Partial or intermediate harvest cutting offers desirable biological advantages, but raises obvious questions of economic feasibility, residual stand response, stand damage, and management constraints. The research undertaken was in part an effort to shed light on these kinds of questions and concerns.

A principal collaborator with the Program in this research has been the Intermountain Station's Subalpine Forest silviculture unit located in Bozeman, MT. The nature of the questions being addressed necessarily involved close coordination between silviculture and utilization. Stand treatment and evaluation typically involves the following sequence of events:

1. Stand treatment specification (silviculture).

2. Harvesting and utilization operations (utilization).

3. Evaluation of postharvest responses (silviculture and other biological sciences).

<u>Field Study Sites</u>--Much of the research has been carried out at a series of field sites selected to represent as wide an array as possible of stand age, tree size, and density, within natural stands 3 to 7 inches in average diameter at breast height (d.b.h.).

Twenty-five stands were selected with the aid of Forest and District personnel. Basic selection criteria for sample stands included:

1. Stand diameters averaging 6 inches or less (d.b.h.); stand considered precommercial for sawtimber.

2. Site index class SI_{100} = 50 or above.

3. Uniform slope, aspect, and general stand character.

4. Stand age and density generally within the ranges of 50 to 120 years, and 1,000 to 6,500 green stems per acre.

5. Area accessible by existing road, preferably above existing road.

6. Terrain operable with wheeled or tracked harvesting equipment.

With minor exceptions, all selected stands met these criteria. Stand size, age, and density and site are considered the primary biophysical variables likely to influence economic operability and postharvest stand response.

The 25 stands had relatively well-distributed ages and densities, varying from 49 to 122 years in age and 800 to 6,500 green stems per acre (fig. 2). They are located in five National Forests--Deerlodge, Gallatin, Lewis and Clark, Lolo (Montana), and Wasatch-Cache (Utah-Wyoming) (fig. 3).

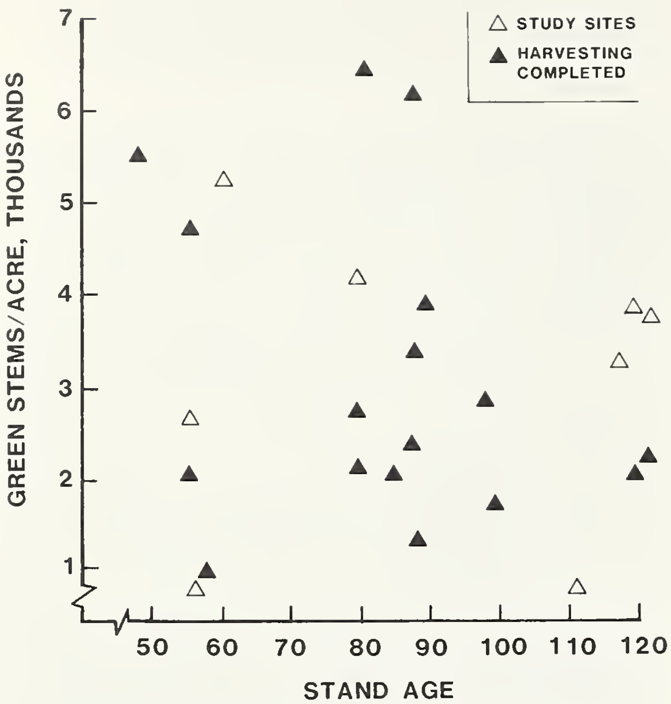

Figure 2--Selected field research sites represented a broad spectrum of stand age and density, with ranges from about 50 to 120 years and 1,000 to 6,500 green stems per acre.

Intensive inventory information was obtained for all selected stands describing the timber resource in detail, as well as understory vegetation and other pertinent biological characteristics of each site. All selected stands are described in detail in an establishment report (USDA Forest Service 1985).

Stand Treatments--Depending upon stand condition and management objectives, stand treatments ranging from clearcutting to intermediate harvest cutting or thinning are all potentially viable options in small lodgepole pine. An objective of this series of studies was to evaluate an array of silvicultural and utilization practices, with special emphasis on intermediate harvest cutting. Treatment options involved adjusting stand densities to different levels. An initial decision had to be made regarding the specific treatment criteria that would be used to specify stand treatments. The following two approaches appeared most viable:

1. Set posttreatment stand densities at specific numbers of trees per acre and remove all but those reserve trees regardless of the original basal area and number of trees. This alternative results in a wide variance of basal area stocking of reserve trees.

2. Set specific levels of basal area reduction based on percent of the unmanaged stand basal area. This alternative results in a wide range of reserve tree numbers per acre.

We chose the latter because we felt it was more compatible with the stand conditions and study objectives. An important distinction to note is that treatments chosen for research purposes are not necessarily valid management prescriptions. Rather, they satisfy experimental design requirements, and ultimately contribute to the development of management prescriptions.

Figure 3--Field research sites were geographically distributed from northern Utah to Montana, with the majority in west-central Montana.

The silvicultural treatments chosen for experimentation included two levels of intermediate cutting. "Light" and "heavy" levels of cutting were defined as reductions in preharvest green stem basal area (BA) of 33 and 66 percent, respectively. The treatments were specified in terms of BA reduction for several reasons:

- Percentage reduction of pretreatment BA is a relatively easy way to calculate and apply a uniform treatment to widely variable stands.

- Other research that has been conducted to examine stand responses to treatment (for example, wind damage) has keyed on BA level as a primary independent variable.

- BA in natural stands is an indicator of site potential or "carrying capacity;" consequently, the level of release provided by intermediate harvest cutting is somewhat proportional to BA reduction.

-- Applying a constant BA reduction to stands differing in average tree size and stand density results in an adjusted residual tree spacing--dense, small-diameter stands are left with relatively close residual stand spacing; larger diameter, more open stands are left with a correspondingly wider spacing.

-- A specific BA reduction prescription provides a constant or benchmark treatment, within which effects of variables such as tree size, age, and stand density can be evaluated. Effects of stand age on residual tree response, for example, must be evaluated in terms of some constant or uniform treatment.

As indicated earlier, not all the stand treatments resulting from this specification would be likely candidates for broad management application. For example, a 33 percent BA reduction in smaller diameter, very dense stands results in a residual stand that is still too closely spaced for management purposes that seek to maximize timber growth. Nevertheless, research objectives are well served by establishing treatments that cover the full array of possibilities, ideally extending beyond the bounds of usual or proposed practice. The application of 33 and 66 percent BA reduction treatments to the wide variety of stands selected resulted in postharvest residual stand spacing ranging from 4 to 17 feet.

Harvesting and utilization specifications for the units were established to attempt to maximize product recovery from cut stems, and to leave a clean, undamaged residual stand for subsequent long-term evaluations of tree response and growth, as well as other biological responses. Harvesting requirements were that all cut trees 3 inches or more in diameter at the stump had to be removed from the unit (older dead excepted). Trees smaller than 3 inches could be left on site, but had to be slashed to lengths of 6 feet or less.

In summary, stand treatments on the study units included:

Stand treatment	Required removal	Residue treatment
1. Light cut (33 percent BA reduction)	Whole-stem, 3 inches plus at stump	Slash on site
2. Heavy cut (66 percent BA reduction)	Whole-stem, 3 inches plus at stump	Slash on site
3. Clearcut (selected units only)	Whole-stem, 3 inches plus at stump	Slash; broadcast burn
4. Control	--	--

Field Operations--Each study stand or unit was established and laid out to include the two levels of intermediate harvest--33 percent and 66 percent BA reduction--plus an untreated control. A few sites, such as the unit illustrated in figure 4, included a clearcut subunit. Most study sites were 5 to 10 acres, with treatment subunits ranging from 1.1 to 3.7 acres and averaging about 2 acres each. Permanently monumented sample points were established in each subunit as a basis for pre- and posttreatment inventory and site evaluation. A number of residual trees around each point are also permanently identified to provide a basis for evaluating response to treatment.

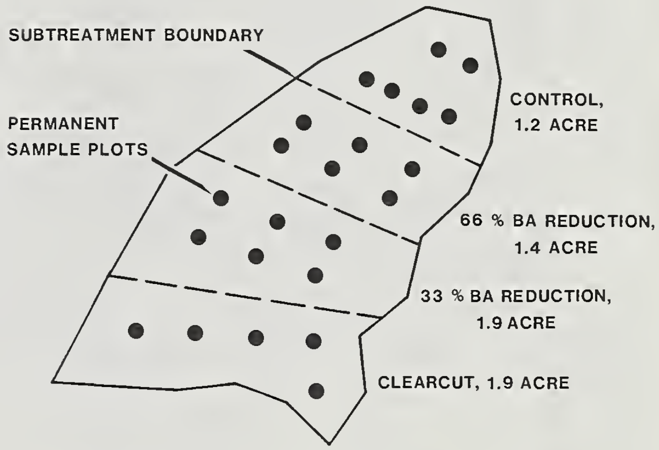

Figure 4--Study units were laid out to include two levels of intermediate harvest and a control subunit. A few also included a clearcut subunit.

Harvesting was carried out with a wide variety of equipment and methods, depending on the capabilities and preferences of successful bidders. Systems ranged from hand operations typical of thinning, to mechanized systems more typical of commercial logging (fig. 5). To avoid masking over or confounding effects of BA reduction, and to maintain maximum comparability among subunits treated by the same treatment, no equipment was allowed in the subunits. Equipment was allowed to enter the stand only on designated skid roads that generally coincided with subunit boundaries. Movement of stems from stump to skid road had to be by hand or by line (winch) skidding. Product recovery was at the option of the contractor, and was encouraged by the requirement that all cut green stems 3 inches and larger be removed from the unit. Actual product recovery varied with market opportunities, distance to buying yards, and the inclination of the contractor.

MAJOR RESEARCH EMPHASIS

The principal areas of research emphasis include silvicultural practices, harvesting and utilization practices, and management consequences of stand treatment. Within each of these broad research areas, several studies have been conducted.

Silvicultural Practices--A major management concern in small lodgepole pine is development of silvicultural treatments that can most effectively promote stand growth and development, and

Figure 5--Harvesting equipment ranged from conventional logging equipment to older non-conventional equipment like the tractor and skidding trailer shown.

reduce susceptibility of stands to insect attack, disease, windthrow, and other such factors. Long-term growth response to intermediate cutting is not presently well established in stands that have long histories of overstocking. Neither are the interactions between growth response and various stand conditions and treatment practices well defined.

Current emphasis in this Country and Canada is directed toward developing long-term management options for lodgepole pine that will break up extensive homogeneous stands and create mosaics of different age classes, species composition, and stand densities. Mountain pine beetle infestations continue to be a primary concern in larger lodgepole pine. An important objective of silvicultural treatments in small-stem stands is to develop stands that are less predisposed to beetle attack. This objective may be achieved in part through developing greater age class diversity among stands, improving growth and vigor, and reducing rotation ages.

This research provided an opportunity to impose alternative intermediate harvesting treatments on small-stem lodgepole pine stands of varying (and known) age and stocking density (fig. 6). Early results reported in this proceedings indicate costs and feasibility of treatment, damage to residual stands from natural causes, and treatment influences relating to other resources. The sites will continue to be monitored and sample trees remeasured periodically for a number of years, to fully evaluate stand and site response to treatment.

Harvesting Feasibility and Product Recovery--Harvesting trees--the removal of all or some part of a stand--is the principal means available to managers to achieve multiresource management objectives on timbered lands. The obvious problem in small-stem stands is the high cost of harvesting numerous small stems with conventional technology, coupled with the typically low value of products recovered. In the kind of stands represented by small lodgepole pine, harvesting costs have historically severely limited stand treatment feasibility. Opportunities exist, however, to improve the situation at both ends of the spectrum. Harvesting technology better suited to small stems is being developed, and markets for small roundwood and wood fiber of any kind are generally improving.

The treated units represented a typical cross section of the harvesting problems and product recovery opportunities inherent in small-stem lodgepole pine stands on gentle terrain. Costs, rates of production, and product recovery were determined for the systems and practices used by the contractors, using both contractor daily records and on-site observations by researchers. Results provide an indication of the economic feasibility of stand treatment and an assessment of the extent to which preharvest stand conditions influence economic feasibility.

Product recovery and associated value is a particularly essential part of any treatment feasibility assessment (fig. 7). A significant research effort went into development and verification of a product prediction model for round-

Figure 6--Pictured is a treatment subunit in which the 66 percent basal area reduction prescription was applied. Stand density was reduced from over 6,000 green stems per acre to 686 stems per acre.

Figure 7--Product recovery from treated stands included post, pole, rail, and "grape-stake" (agricultural and landscaping stake) products.

wood products in lodgepole pine 3 to 7 inches in diameter. The model provides a consistent and unbiased approach to appraising product options and values in stands being considered for treatment. The combination of treatment costs and predicted recoverable product values provides the best approach to identifying those stands that offer the most attractive economic opportunity.

Management Consequences of Harvesting--A major justification for harvesting in presently submarginal stands is to facilitate timber management in the stand, to manage or influence other resources and uses on the site and to reduce susceptibility to insect, disease, and fire damage. Objectives relating to regeneration, improved growth, esthetics, wildlife habitat, watershed management, fire management, insect control and other such concerns often depend on carrying out prescribed harvesting activities. Whether or not such objectives are defined, stand modification through harvesting leads to significant biological and economic consequences for virtually all resources.

The investigation of biological consequences has centered on silvicultural effects (discussed earlier) and on nontimber vegetative responses. Broad resource management implications of harvesting are often either directly or indirectly the result of altering vegetative cover and composition. Program research has been directed toward

identifying and characterizing existing understory plant communities (as the initial basis for vegetative response), developing a model capable of predicting vegetative response and plant community development following harvesting, and relating predicted responses to resource management. The research provides a basis for more effectively assessing the multiresource management consequences of any contemplated stand treatment.

Using harvesting treatments to achieve a combination of timber-oriented and nontimber management objectives raises economic questions of costs incurred and benefits achieved, now and in the future. To make valid decisions among treatment alternatives, managers need to be able to evaluate tradeoffs in economic terms. Of particular importance are identifying economic opportunity costs associated with constraints imposed to protect or enhance nontimber resource values, direct investment costs associated with nontimber management objectives, and the mix of resource values accruing from specific harvesting treatments. For the treatments applied to small-stem lodgepole pine stands, Program research has attempted to identify both the nontimber and timber resource management objectives of concern and define costs and benefits associated with them. Because relative benefits to various nontimber resources change over time (for example, changes in wildlife habitat or visual quality), an analysis of time trends is also an important aspect of this research.

APPLICATION TO THE PROBLEM

This proceedings, and the workshop upon which it is based, are intended to report recent research that can be useful in solving the resource management problem posed by small-stem stands of lodgepole pine. It includes the silvicultural, utilization, and biological response research conducted at the field sites I have described. It also includes discussions of research conducted at other similar sites--the University of Montana's Lubrecht Experimental Forest and Champion Incorporated company lands, for example--and discussions of product, market, and other research not associated with specific field sites.

Information presented here generally does not provide "cookbook" recommendations or final answers to management issues in small lodgepole pine. In the limited time since stand treatment, only initial postharvest effects can be determined with confidence. Rather, the models, analyses, and projections developed and discussed can provide managers with a better understanding of the management implications of any stand treatment, and an improved knowledge of factors critical to stand and site response.

Altogether, participants in this effort over the past 5 years have included Forest Service researchers and land managers, University researchers, industry collaborators, and consulting foresters and researchers. It is our collective hope that the results will provide a basis from which managers can judge the feasibility and both short- and long-term desirability of alternative stand treatments and utilization practices for small lodgepole pine.

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Harvesting Practices and Costs

Chaired by: Michael J. Gonsior

Timber harvesting is the principal means by which multiresource management objectives are pursued on forested lands. Commercial products are recovered and stand and site conditions are altered to meet appropriate resource management prescriptions. Small-stem lodgepole pine often presents severe economic feasibility problems, however, due to inherently high harvesting costs and low product values. Needed are harvesting systems and techniques that can operate more effectively in small-stem stands. Development of new mechanization, prebunching, whole tree handling and processing, and improved system organization are among the approaches that may improve efficiency. Discussed in this section are some of the systems and practices that can contribute to improved harvesting feasibility in small lodgepole pine.

TIMBER HARVESTING FEASIBILITY IN SMALL-STEM LODGEPOLE PINE

Charles H. Hawkins, III

ABSTRACT: Management of small-stem (averaging less than 6 inches in diameter at breast height) lodgepole pine is a major problem in the Rocky Mountain West. Costs of desired silvicultural treatments in these stands generally exceed the value of recovered products. Improved harvesting techniques and product utilization would enable forest managers to offset larger portions of stand treatment costs. Thus, more of this immense resource could be brought under management with the limited funds available.

INTRODUCTION

This study was designed to evaluate opportunities for cost reduction and revenue generation in harvesting small-stem lodgepole pine. Operations on 11 study units were assessed for productivity, cost, and product recovery. It was apparent that the contractor's experience, skill, organization, and motivation had more bearing on productivity than did the specific harvesting system. The most significant variables affecting treatment costs were found to be level of basal area reduction, number of trees designated for cutting that were 3 inches or larger, and intensity of product salvage and manufacture. Product recovery value was also strongly influenced by these variables, as well as by local markets.

Study results indicate that investments should be concentrated on the best sites where a combination of tree density, size, and form result in highest predictions of product value. Tree-length harvesting and marketing appears to be the most cost-effective method of operation. Cost reduction and revenue generation can be improved by contractors who refine their basic technical, management, and marketing skills.

BACKGROUND AND OBJECTIVES

Much of the Rocky Mountain West is forested with overstocked stands of small-stem lodgepole pine. These present a major problem for resource managers. Because of high harvesting costs and low product values timber harvest returns alone can seldom be relied upon to cover the cost of desired silvicultural treatment.

The studies undertaken were principally intended to identify opportunities for reducing harvest costs and increasing product revenues. While admitting that few stands of small-stem lodgepole pine can generate sufficient revenue to pay for intensive silvicultural treatment, and it may not be feasible to treat many stands under any circumstances, we hoped to gain some practical insights that would enable forest managers to treat slightly submarginal stands at reduced net costs. We wanted to determine how various preharvest stand conditions, as well as specified treatment variables, affected harvesting productivity and cost. We also wanted to compare stands in terms of treatment feasibility, to discover the most productive harvesting systems and techniques, and to assess the potential products and values that can be recovered from treated stands.

STUDY SITES

As part of a larger interdisciplinary study, 25 study sites were established across the Forest Service Northern and Intermountain Regions. Ostensibly, these study sites described the range of small-stem lodgepole pine stand conditions in the Intermountain West. Stands selected portrayed a wide range of stocking densities, ages, site indices, and tree sizes, and stand compositions of saplings and poles with average breast-height diameters well below 6 inches. All study sites were accessible by existing roads, situated on uniform slopes, and operable with conventional wheel or track harvesting equipment. Figure 1 shows a typical stand before harvest.

Figure 1--Typical study site preharvesting stand conditions.

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Harvesting component costs and actual product recovery, as well as predicted product recovery, were analyzed on 11 of these study units in the Northern Region. These 11 units included 25 treatment subunits. Treatments on the other 14 study units were either not completed or so compromised that the results could not be used for analysis of harvesting and utilization alternatives. Table 1 compares preharvest stand conditions for the 25 treatment subunits included in this analysis.

All 11 study sites are located in Montana. Rattling Gulch and the three Corduroy units are in the Upper Willow Creek drainage, 23 to 26 miles northwest of Philipsburg. Echo Lake is about 2 miles north of Georgetown Lake. Ballard Hill North is some 10 miles south of Gold Creek. All six of these units are in the Deerlodge National Forest.

Four study sites are 30 to 60 miles north of White Sulphur Springs in the Lewis and Clark National Forest. Currie Coulee North and the two Dry Fork units are 3 to 4 miles east of Monarch in the Dry Fork drainage. Wet Park is about 20 miles southwest of Neihart near Kings Hill Pass. South Flat lies 2 miles south of West Yellowstone in the Gallatin National Forest.

Detailed descriptions of all study site locations and conditions, along with some postharvest information and much additional pertinent data, can be found in the STEM Program Establishment Report "Harvesting and Silvicultural Alternatives in Small-Stem Lodgepole Pine Stands" (Barger 1985).

Table 1--Comparison of stand conditions (on a per-acre basis)

Treatment unit and subunit	Subunit area	Stand age	Site index	Stems /acre	BA /acre	Average d.b.h.	Average slope
	Acres	Years	Index	No.	Ft^2	Inches	Pct
Rattling Gu T-1	1.33	59	83	1,086	144	4.60	5
Rattling Gu T-2	1.47	59	83	863	135	4.97	5
Corduroy E T-1	1.86	85	78	2,875	237	3.66	8
Corduroy E T-2	1.39	85	78	3,058	214	3.33	8
Corduroy E T-3	1.86	85	78	3,240	228	3.31	8
Corduroy W T-1	1.76	88	69	5,444	221	2.54	8
Corduroy W T-2	1.55	88	69	3,851	233	3.08	8
Corduroy N T-1	3.66	86	70	9,264	221	1.94	8
Corduroy N T-2	3.19	86	70	9,400	250	2.04	8
Echo Lake T-1	2.12	88	70	9,317	281	2.10	20
Echo Lake T-2	2.53	88	70	8,329	267	2.19	20
Currie N T-1	1.18	54	82	3,140	169	2.90	30
Currie N T-2	1.29	54	82	5,280	183	2.23	30
Dry Fork E T-1	2.24	57	77	7,277	187	1.93	22
Dry Fork E T-2	2.16	57	77	5,056	177	2.32	22
Dry Fork W T-1	1.26	56	77	5,334	153	2.05	22
Dry Fork W T-2	1.19	56	77	8,354	174	1.71	22
Wet Park T-1	1.52	88	66	6,885	273	2.48	2
Wet Park T-2	1.38	88	66	4,689	300	3.14	2
Wet Park T-3	.99	88	66	4,200	248	3.02	2
Ballard N T-1	1.80	80	94	3,265	306	3.78	20
Ballard N T-2	1.55	80	94	4,271	357	3.57	20
South Flat T-1	1.56	89	63	3,436	227	3.26	5
South Flat T-2	1.35	89	63	3,150	219	3.34	5
South Flat T-3	1.29	89	63	4,250	159	2.48	5

TREATMENT SPECIFICATIONS

Treatments were specified to meet multidisciplinary research objectives. For harvesting operations, requirements were quite demanding and restrictive. It is important to remember this when considering the costs incurred.

To provide a range of treatments, each study unit was divided into several subunits, ranging in size from 0.99 to 3.66 acres. Each unit included subunits targeted for 33 and 66 percent basal area reduction. These reductions resulted in an array of leave-tree spacings ranging from 4.0 to 17.5 feet. In some cases, a clearcut subunit also was included. All study sites had an uncut control area.

In partial-cut subunits, the operator was instructed to select the largest, best formed, and healthiest trees that conformed to a specified leave-tree spacing guide. Only a small sample area was premarked for the operator.

All cut trees 3.0 inches in diameter or larger at stump height were required to be removed from the unit. Whole-tree (including top) removal was required to simulate salvage of all potentially merchantable stems and to satisfy slash disposal objectives. Actual salvage of salable products was encouraged, but not mandatory. Trees and parts of trees not salvaged were bucked into 6-foot maximum lengths and piled outside the unit boundary. Cut trees smaller than 3.0 inches in diameter at stump height were slashed into 6-foot maximum lengths and left in place on site. Figures 2 and 3 show postharvest stands where basal area was reduced 33 and 66 percent.

Figure 2--Typical postharvest stand condition after 33 percent basal area reduction.

Neither road construction nor operation of wheel or track vehicles was permitted within the treatment subunit. But stump road and skid trail construction was permitted as necessary to access all unit perimeters. Road and trail development was also allowed along the common internal boundaries of adjacent subunits.

Figure 3--Typical postharvest stand condition after 66 percent basal area reduction.

Harvesting requirements and operating constraints were strictly enforced. This ensured the consistent treatment necessary for concurrent and subsequent multidisciplinary studies on these sites. Some notable exceptions which were allowed were:

> On the Wet Park clearcut (T-3), the contractor was permitted to use a small crawler tractor equipped with a tree shear for felling and skidding.
>
> To compensate for steep slopes (exceeding 30 percent) and excessive forwarding distance (up to 800 feet) on Currie Coulee North, the contractor was permitted to construct a skid trail through the unit. The crawler-mounted shear was used to cut right-of-way on this trail.

Table 2 compares the treatment specifications for all 25 subunits.

HARVESTING SYSTEMS AND METHODS

Contractors working under service contracts awarded through competitive bidding performed all treatments. Within limits of treatment specifications, contractors were permitted total latitude in choice of harvesting systems, equipment, and salvage and sale of merchantable products. Work began in fall 1982 and progressed spasmodically through the 1983 and 1984 field seasons.

Because of the variety of site conditions and locations, we anticipated that a wide variety of innovative methods and equipment would be employed and that a broad array of products would be salvaged. But in fact, all systems were quite conventional and labor-intensive, and salvage was generally limited to an assortment of post and pole products. Figure 4 shows equipment used in a typical hand-labor harvesting operation.

Table 2--Comparison of stand treatments (on a per-acre basis)

Treatment unit and subunit		Residual[1] Spacing	Stems	BA removed	Stems cut	Stems cut and removed	
		Feet	No.	Pct	- - Number - -		Ft³
Rattling Gu	T-1	11.00	400	39	686	468	1,188
Rattling Gu	T-2	17.50	241	48	622	468	1,513
Corduroy E	T-1	6.50	1,091	35	1,784	676	1,319
Corduroy E	T-2	11.00	475	65	2,583	1,208	2,666
Corduroy E	T-3	--	0	100	3,240	1,620	4,877
Corduroy W	T-1	6.00	1,943	34	3,501	328	453
Corduroy W	T-2	10.50	614	60	3,237	1,112	2,112
Corduroy N	T-1	4.00	3,264	32	6,000	0	0
Corduroy N	T-2	7.50	1,186	66	8,214	656	793
Echo Lake	T-1	5.00	1,601	58	7,716	951	1,668
Echo Lake	T-2	8.50	686	79	7,643	1,443	2,482
Currie N	T-1	6.50	930	48	2,210	600	1,017
Currie N	T-2	11.50	350	81	4,930	1,110	1,857
Dry Fork E	T-1	5.50	1,327	57	5,950	475	616
Dry Fork E	T-2	9.50	544	77	4,512	1,034	1,452
Dry Fork W	T-1	5.50	1,578	42	3,756	212	254
Dry Fork W	T-2	9.50	600	78	7,754	566	658
Wet Park	T-1	7.00	701	78	6,184	1,441	2,434
Wet Park	T-2	12.00	315	88	4,374	1,887	4,614
Wet Park	T-3	--	0	100	4,200	1,925	4,138
Ballard N	T-1	6.50	1,149	31	2,116	815	1,612
Ballard N	T-2	11.00	250	83	4,021	2,085	6,983
South Flat	T-1	6.00	1,036	42	2,400	757	1,178
South Flat	T-2	10.50	429	71	2,721	1,271	2,724
South Flat	T-3	--	0	100	4,250	1,125	1,007

[1]Target spacing, actual stems.

Figure 4--Equipment used in typical hand-labor harvesting operation.

Haul Roads, Skid Trails, and Landings

Our intent was to locate study sites reasonably close to existing haul roads. Two subunits (Rattling Gulch T-1 and Echo Lake T-2) were adjacent to such roads. The remainder were accessed by opening old spurs or building minimum-standard stump roads and skid trails. Operators typically constructed trails along three quarters of the subunit perimeter and forwarded merchantable products about 400 feet to centralized landings or roadsides.

Stump roads and skid trails were cleared with crawlers, skidders, or hand labor as available. Merchantable products were usually salvaged from some of the larger trees and residual slash was piled along the right-of-way. The character of the road and trail clearing operations tended to parallel the methods used within adjacent treatment units. Landings were located in natural or

existing openings and seldom caused much additional clearing.

Harvesting Systems and Methods

Following are cursory descriptions of the two prevalent systems used by the several contractors. These can be categorized broadly as product-length and tree-length operations.

Product-Length Operations--These were used at Rattling Gulch, Corduroy East, and Corduroy West, Corduroy North (all operated by one prime contractor and one subcontractor), and Echo Lake, which was operated by a second contractor. These operations were well organized and reflected an air of knowledge, experience, and efficiency by contractor personnel.

Crews consisted of one man working alone or of two to four people working in concert. Leave-tree selection and product manufacture was always done by the faller. Bucking was always done directly after felling and merchantable products, nonmerchantable material (slashed to 6-foot lengths), and tree tops were immediately hand-carried to the unit boundary. Salvaged pieces were piled by product classification and nonmerchantable material was piled for burning. Trees smaller than 3.0 inches at stump height were slashed into 6-foot or shorter lengths directly after felling and left on the site. The system seldom varied, although the crews occasionally prethinned small trees in the denser stands and sometimes deferred slashing small felled trees until a later time.

From the unit boundary, merchantable products were forwarded to a centralized landing or roadside where they were usually cold-decked for future loading and hauling to market. Hot-loading was rare. The contractors at the Rattling Gulch and Corduroy units used an antiquated farm tractor and homemade trailer for forwarding. At Echo Lake, the contractor used a vintage small crawler tractor. This old equipment was in good repair and was generally available when needed for limited light-duty use. Products were loaded by hand and hauled to market on small flatbed or pickup trucks.

Tree-Length Operations--This was the principal method used over most of the area at Currie Coulee North, Dry Fork East, Dry Fork West, and Wet Park (all of which were operated by the same contractor), as well as at Ballard Hill North and South Flat, which were operated by another contractor.

These operations were characterized essentially by tree-length removal from the unit and forwarding to centralized landings where products were bucked and nonmerchantable material was piled. But specific procedures varied quite radically as the contractors progressed and experimented with their harvesting systems. Occasionally, the system was completely compromised and more closely resembled the product-length methods. Crews at these units tended to be larger, less experienced, and poorly organized.

Most of the time, trees smaller than 3.0 inches were prethinned to some extent with slashing deferred until all other work was completed. Leave-tree decisions were made by the fallers at Ballard Hill North and South Flat. At Currie Coulee North, Dry Fork East, Dry Fork West, and Wet Park leave-trees were premarked by the contractor. Trees 3.0 inches and larger were felled directionally and either winched or hand-dragged to the subunit boundary. Prebunching by hand was found to improve the productivity of equipment used for winching.

Small skidders and crawlers were used to winch trees from the units and forward them to landings. They were also used for road, trail, and landing construction, for maintenance of these facilities, and for slash piling. All equipment tended to be grossly underutilized in terms of scheduled time, idling time, and payload capacity. Much of this equipment was in poor repair and often unavailable for work when needed.

Trees removed from the units were disposed of in several ways. Methods ranged from cold-decking in tree-length form for later salvage, to immediate manufacture and cold-decking in product form, to occasional hot-logging, in which products were manufactured and loaded as soon as the trees reached the landing. Where merchantable products were not salvaged, trees removed were usually slashed and piled at the unit boundary. Specific methods tended to vary radically both between and within treatment subunits.

At the Dry Fork and Wet Park units, merchantable products were loaded with a small wheel-driven front-end loader and hauled on a flatbed truck. (No products were salvaged from the Dry Fork T-1 subunits or from Currie Coulee North.) Conventional self-loading log trucks hauled a few small sawlogs and houselogs from Ballard Hill North and South Flat; but the majority of merchantable material from these units was hand loaded and hauled on light-duty short-log or small flatbed trucks. Table 3 summarizes the labor and equipment hours expended at each of the 25 subunits.

DATA COLLECTION

Production summaries were based on a combination of operator reporting, field verification, and preharvest and postharvest inventories. Inventory work was done by Intermountain Research Station field crews and processed by Station personnel in conjunction with concurrent studies.

Stump road and skid trail construction time and right-of-way product recovery data were compiled. But only data from those portions actually within the unit boundaries were included in this analysis. Data from roads and trails along common internal boundaries were divided evenly between the adjacent subunits.

Because of the inherent errors, omissions, and inconsistencies of operator reporting, and the variation encountered in stand and product sampling, these production results are presented with some reservation. Although this information is

Table 3--Labor and equipment time (on a per-acre basis)

Treatment unit and subunit		Labor		Equipment		Total[1]	
		Cut	Remove	Cut	Remove	Labor	Equipment
		Hours					
Rattling Gu	T-1	42	60	42	0	102	42
Rattling Gu	T-2	40	61	40	3	101	43
Corduroy E	T-1	26	30	26	3	56	29
Corduroy E	T-2	55	59	55	1	114	56
Corduroy E	T-3	85	125	85	21	210	106
Corduroy W	T-1	46	29	46	0	75	46
Corduroy W	T-2	85	99	85	5	184	90
Corduroy N	T-1	31	0	31	0	31	31
Corduroy N	T-2	29	30	29	1	59	30
Echo Lake	T-1	74	52	74	0	126	74
Echo Lake	T-2	125	85	125	0	210	125
Currie N	T-1	59	28	45	0	87	45
Currie N	T-2	59	29	46	0	88	46
Dry Fork E	T-1	48	30	48	3	78	51
Dry Fork E	T-2	112	63	99	27	175	126
Dry Fork W	T-1	69	25	50	13	94	63
Dry Fork W	T-2	99	126	79	47	225	126
Wet Park	T-1	55	16	45	11	71	56
Wet Park	T-2	118	162	102	72	280	174
Wet Park	T-3	171	67	172	61	238	233
Ballard N	T-1	40	58	40	13	98	53
Ballard N	T-2	52	46	52	46	98	98
South Flat	T-1	94	108	93	10	202	103
South Flat	T-2	118	111	117	7	229	124
South Flat	T-3	160	259	160	77	419	237

[1]Includes cutting, removal, slash treatment, and forwarding time; does not include access road or landing construction time.

less than exact, it still provides reasonable approximations that are adequate for comparative purposes.

LABOR AND EQUIPMENT COST BASIS

To provide a consistent basis for comparing relative costs among treatment subunits, harvesting systems, and operators, standard labor and equipment rates were applied to reported operating time. Parallel analyses were made using two separate sets of assumptions.

Table 4 shows the labor and equipment rate assumptions used in the first analysis. They typify rates paid and costs incurred by the contractors who participated in this study. These rates were formulated by consensus of several researchers who are studying small-stem harvesting costs.

A second set of assumptions is shown in table 5. These are adapted from the Forest Service Manual timber sale appraisal section for the Northern Region. They indicate cost allowances that might be required to attract high-volume contractors for extensive stand treatments. A concomitant assumption might be that higher labor and equipment rates would engender corresponding productivity increases. But this hypothesis has not been tested and is not considered in the analysis.

FELLING AND SLASHING COSTS

Table 6 summarizes costs of felling and slashing trees required to be cut. These costs are based on labor and equipment time shown in table 3 and on labor and equipment rates shown in table 4. They incorporate all costs incurred in felling and slashing as well as the additional costs of limbing, measuring, and bucking engendered by optional salvage of salable products. Such functions were charged to cutting (felling and slashing) whether they were performed at the stump, adjacent unit boundary, or a remote landing.

Felling and slashing costs shown in table 6 indicate what a forest manager might have to pay for comparable treatments in similar stands,

Table 4--Labor and equipment rates (on a per-hour basis)[1]

Item	Base	Pay-roll	Over-head	Total
	Dollars			
Labor:				
Sawyer (w/o saw)	6.00	2.00	0.72	8.72
Equipment operator	6.00	2.00	.72	8.72
General laborer	6.00	2.00	.72	8.72
Equipment:				
Chainsaw	1.50	--	--	1.50
Skidders and tractors	12.00	--	--	12.00

[1]Based on consensus of several researchers studying small-stem harvesting costs.

Table 5--Alternative labor and equipment rates (on a per-hour basis)[1]

Item	Base	Pay-roll	Over-head	Total
	Dollars			
Labor:				
Sawyer (w/o saw)	9.08	3.00	1.45	13.53
Equipment operator	8.95	2.95	1.43	13.33
General laborer	8.95	2.95	1.43	13.33
Equipment:				
Chainsaw	2.27	--	--	2.27
Skidders and tractors	20.94	--	--	20.94

[1]Adapted from Forest Service Manual 8/82 R-1 (Northern Region) Supplement 293.

assuming all cut trees can be slashed and left in place. Actually, the manager might expect to perform such treatments at slightly lower costs than those shown here. This is because our study included those additional cutting costs implicitly associated with required removal and optional salvage (for example, directional felling, limbing, measuring, and bucking).

ADDED COST OF REQUIRED REMOVAL

In table 7, the cost of requiring that all cut trees 3.0 inches and larger be removed from units is added to cutting costs. Removal costs include such activities as piling and prebunching, hand carrying and dragging, choker setting and winching, skidding and forwarding, product sorting and decking, and slash piling. As with cutting costs, such functions were charged to removal cost regardless of point of performance.

Table 6--Costs of felling and slashing (on a per-acre basis)[1]

Treatment unit and subunit		Labor	Equipment	Total
		Dollars		
Rattling Gu	T-1	366	63	429
Rattling Gu	T-2	349	60	409
Corduroy E	T-1	227	39	266
Corduroy E	T-2	480	83	562
Corduroy E	T-3	741	128	869
Corduroy W	T-1	401	69	470
Corduroy W	T-2	741	128	869
Corduroy N	T-1	270	47	317
Corduroy N	T-2	253	44	296
Echo Lake	T-1	645	111	756
Echo Lake	T-2	1,090	188	1,278
Currie N	T-1	514	139	653
Currie N	T-2	514	200	714
Dry Fork E	T-1	419	72	491
Dry Fork E	T-2	977	149	1,125
Dry Fork W	T-1	602	75	677
Dry Fork W	T-2	863	119	982
Wet Park	T-1	480	92	572
Wet Park	T-2	1,029	214	1,243
Wet Park	T-3	1,491	1,179	2,670
Ballard N	T-1	349	60	409
Ballard N	T-2	453	78	531
South Flat	T-1	820	140	959
South Flat	T-2	1,029	176	1,204
South Flat	T-3	1,395	240	1,635

[1]Includes all costs of felling and slashing, plus the costs of limbing, measuring, and bucking optional salvaged products.

Table 8 summarizes cutting and removal costs in terms of the higher alternative labor and equipment rates shown in table 5.

Removal costs shown in tables 7 and 8 do not indicate what an operator might expect to spend on product recovery under conventional treatment prescriptions. This is because our requirements included stringent silvicultural study constraints such as removal of nonmerchantable material and exclusion of machinery from the units. Removal costs and total costs summarized here are intended to illustrate relative results under this set of research requirements. Under more typical operating circumstances--where the contractor need only remove merchantable material and where equipment can be operated throughout the unit (or at least on more closely spaced trails)--one would expect the incremental costs of product removal to be substantially lower than those in our study.

Table 7--Costs of total stand treatment (on a per-acre basis)

Treatment unit and subunit		Labor		Equipment		Total		Total		Grand total[1]
		Cut	Remove	Cut	Remove	Labor	Equipment	Cut	Remove	
		Dollars								
Rattling Gu	T-1	366	523	63	0	889	63	429	523	952
Rattling Gu	T-2	349	532	60	36	881	96	409	568	977
Corduroy E	T-1	227	262	39	36	488	75	266	298	563
Corduroy E	T-2	480	514	83	12	994	95	562	526	1,089
Corduroy E	T-3	741	1,090	128	252	1,831	380	869	1,342	2,211
Corduroy W	T-1	401	253	69	0	654	69	470	253	723
Corduroy W	T-2	741	863	128	60	1,604	188	869	923	1,792
Corduroy N	T-1	270	0	47	0	270	47	317	0	317
Corduroy N	T-2	253	262	44	12	514	56	296	274	570
Echo Lake	T-1	645	453	111	0	1,099	111	756	453	1,210
Echo Lake	T-2	1,090	741	188	0	1,831	188	1,278	741	2,019
Currie N	T-1	514	244	139	0	759	139	653	244	898
Currie N	T-2	514	253	200	0	767	200	714	253	967
Dry Fork E	T-1	419	262	72	36	680	108	491	298	788
Dry Fork E	T-2	977	549	149	324	1,526	473	1,125	873	1,999
Dry Fork W	T-1	602	218	75	156	820	231	677	374	1,051
Dry Fork W	T-2	863	1,099	119	564	1,962	683	982	1,663	2,645
Wet Park	T-1	480	140	92	132	619	224	572	272	843
Wet Park	T-2	1,029	1,413	214	864	2,442	1,078	1,243	2,277	3,520
Wet Park	T-3	1,491	584	1,179	732	2,075	1,911	2,670	1,316	3,986
Ballard N	T-1	349	506	60	156	855	216	409	662	1,071
Ballard N	T-2	453	401	78	552	855	630	531	953	1,485
South Flat	T-1	820	944	140	120	1,764	260	959	1,064	2,023
South Flat	T-2	1,029	968	176	84	1,997	260	1,204	1,052	2,256
South Flat	T-3	1,395	2,258	240	924	3,654	1,164	1,635	3,182	4,818

[1]Includes cutting, removal, slash treatment, forwarding, and optional salvage costs; does not include access road or landing construction costs.

Table 8--Costs of total stand treatment using higher alternative costs from table 5 (on a per-acre basis)

Treatment unit and subunit		Labor		Equipment		Total		Total		Grand
		Cut	Remove	Cut	Remove	Labor	Equipment	Cut	Remove	total[1]
		- - - - - -	- - - - - -	- - - - - -	- - - - - -	Dollars	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Rattling Gu	T-1	570	802	96	0	1,372	96	666	802	1,467
Rattling Gu	T-2	543	807	91	57	1,350	148	634	864	1,498
Corduroy E	T-1	356	396	60	68	752	128	416	464	878
Corduroy E	T-2	740	786	124	15	1,526	139	864	801	1,665
Corduroy E	T-3	1,157	1,663	194	439	2,820	633	1,351	2,102	3,453
Corduroy W	T-1	623	386	104	0	1,009	104	727	386	1,113
Corduroy W	T-2	1,144	1,316	192	95	2,460	287	1,336	1,411	2,747
Corduroy N	T-1	414	0	69	0	414	69	483	0	483
Corduroy N	T-2	390	401	65	13	791	78	455	414	870
Echo Lake	T-1	998	694	167	0	1,692	167	1,165	694	1,859
Echo Lake	T-2	1,690	1,132	284	0	2,822	284	1,974	1,132	3,106
Currie N	T-1	794	367	229	0	1,161	229	1,023	367	1,390
Currie N	T-2	794	393	337	0	1,187	337	1,131	393	1,524
Dry Fork E	T-1	646	405	108	66	1,051	174	754	471	1,225
Dry Fork E	T-2	1,740	839	225	567	2,579	792	1,965	1,406	3,371
Dry Fork W	T-1	934	336	114	266	1,270	380	1,048	602	1,652
Dry Fork W	T-2	1,342	1,680	179	985	3,022	1,164	1,521	2,665	4,187
Wet Park	T-1	748	210	200	220	958	420	948	430	1,379
Wet Park	T-2	1,598	2,154	340	1,502	3,752	1,842	1,938	3,656	5,595
Wet Park	T-3	2,310	889	2,028	1,269	3,199	3,297	4,338	2,158	6,596
Ballard N	T-1	541	770	91	268	1,311	359	632	1,038	1,670
Ballard N	T-2	698	619	117	973	1,317	1,090	815	1,592	2,407
South Flat	T-1	1,274	1,446	210	201	2,720	411	1,484	1,647	3,132
South Flat	T-2	1,595	1,482	265	147	3,077	412	1,860	1,629	3,490
South Flat	T-3	2,168	3,447	364	1,607	5,615	1,971	2,532	5,054	7,585

[1]Includes cutting, removal, slash treatment, forwarding, and optional salvage costs; does not include access road or landing construction costs.

INFLUENCE OF STAND, TREATMENT, AND HARVESTING VARIABLES

Our field observations and subjective analysis of production data inferred that individual subunit costs might be affected by three interrelated groups of variables:

1. Stand conditions such as tree density, stem size, and ground slope.

2. Treatment specifications including subunit size and shape, basal area reduction, stems cut and removed, and leave-tree spacing.

3. Harvest system design and technique; for example, methods, equipment, forwarding distance, salvage intensity, degree of product manufacture, and operator efficiency.

To see how they influenced total treatment cost, we tested many of these variables in a stepwise multiple regression analysis. Results suggested that only two variables were significant. These were basal area reduction and number of stems 3.0 inches and larger cut and removed. But statistical validity was doubtful due to the number of variables tested.

We also tested several variables by simple two-variable regression analysis to see how they influenced felling and slashing cost. As expected, basal area reduction proved again to have a strong bearing on cost. Also as expected, the importance of the number of stems 3.0 inches and larger cut and removed was proved again. These trends are shown in figures 5 and 6. Analysis of other variables (such as preharvest stems per acre, total trees cut, and average d.b.h.) indicated no significant statistical relationship to felling and slashing cost. Although the number of stems cut must influence cost, the statistical relationship is masked by the large proportion of very small stems (less than 2 inches d.b.h.) that require little effort to cut.

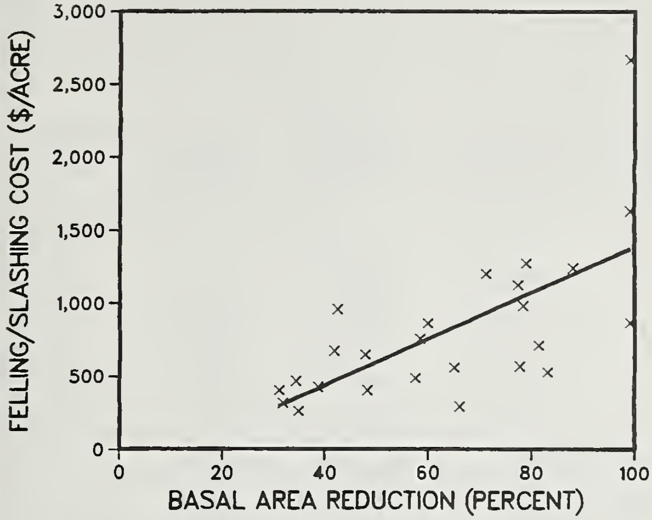

Figure 5--Felling and slashing cost per acre as a function of basal area reduction. Cost of treatment tends to increase with increases in basal area reduction. Cost is represented by the equation y = -189.84 + 15.81x (R^2 = 0.45, SEE = 397.98).

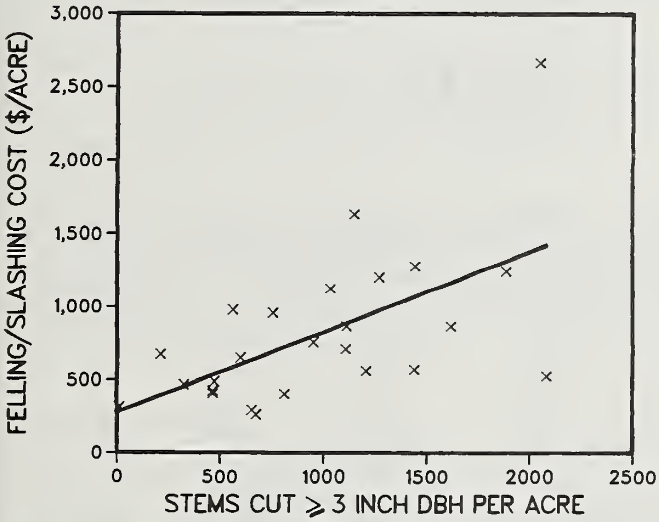

Figure 6--Felling and slashing cost per acre as a function of stems 3.0 inches and larger designated for cutting. Cost of treatment tends to increase with increases in the number of stems 3.0 inches and larger designated for cutting. Cost is represented by the equation y = 279.21 + 0.55x (R^2 = 0.35, SEE = 433.28).

The amount of effort devoted to optional product salvage obviously exerted a potent influence on treatment costs. This was quite apparent from our field observations and subjective analysis of production data. In our multiple regression analysis this variable also proved to be significant, based upon an index that reflected the level of effort devoted to product recovery.

In addition to the problem of myriad variables and limited observations, statistical analysis is further confounded by extreme operational disparities among contractors. Such inconsistencies tend to mask the effect of individual variables.

PRODUCT RECOVERY OPPORTUNITY

The primary products recovered were fenceposts, corral poles, and tree props. Other roundwood products recovered in minor amounts included panel poles, fence braces, barn poles, sawlogs, houselogs, lath logs, and firewood. Figure 7 pictures typical tree-length material decked at the unit boundary for conversion to post and pole products.

Figure 7--Typical tree-length material decked at the unit boundary for conversion to post and pole products.

The extent of salvage and selection of alternative products was obviously a function of tree size, form, and quality, as well as markets and prices. But salvage was also influenced by the vagaries of operator inclination. To some extent, the service contract payments and voluntary salvage option tended to inhibit product recovery, rather than encourage it as originally anticipated.

Our field observations and analysis of production data indicated that the extent of salvage and degree of product manufacture had a pronounced effect on total treatment cost. Operators seemed aware of their diminishing rate of return from intensified salvage.

Actual Product Volume and Value

Recovered products were valued f.o.b. manufacturing points at time of delivery. Piece counts and prices were based on a combination of operator reporting and field verification.

To generate cubic foot volumes and values, average volume per piece was calculated for each product classification. Average piece sizes were based on random samples of products in the field or on estimates of nominal piece size when sufficient samples were not available. Tables 9, 10, 11, and 12 show the sizes, volumes, and delivered values of the products salvaged from the study units.

Table 9--Product classification sample: Rattling Gulch, Corduroy East, Corduroy West, Corduroy North, Echo Lake (1983)[1]

Product	Length	Small-end diameter range	Average diameter: Small-end	Average diameter: Large-end	Volume: Per piece	Value f.o.b. mill: Per piece	Value f.o.b. mill: Per ft^3	Sample size
	Feet	Inches	Inches	Inches	Ft^3	Dollars	Dollars	Pieces
Post	6.5	3.5-5.0	4.1	4.6	0.67	0.52	0.78	45
Post	8.0	5.0-6.0	5.7	6.2	1.55	.80	.52	10
Prop	8.0	1.5-3.8	2.4	2.9	.31	.32	1.03	18
Prop	10.0	1.5-3.8	2.6	3.2	.46	.40	.87	21
Pole	13.0	2.5-3.5	2.8	3.7	.76	1.07	1.41	24
Pole	17.0	1.8-2.5	2.0	3.0	.60	.70	1.17	0
Pole	17.0	2.5-3.5	3.0	3.9	1.12	1.36	1.21	27
Pole	17.0	3.5-4.5	4.0	5.0	1.90	1.75	.92	0
Pole	21.0	2.5-3.5	2.9	3.8	1.31	1.50	1.15	20
Pole	14.0	4.5-5.5	5.0	6.0	2.33	8.40	3.61	0
Pole	22.0	4.5-5.5	5.0	6.0	3.66	13.20	3.61	0
Houselog	12.0	5.0-6.0	5.5	6.5	2.37	7.20	3.04	0
Total								165

[1]Product size classifications and values were provided by operators. Averages were based on a random sample of products in the field (or estimated when not available). Volume was computed from Smalian's formula: V = ((b + t)/2) X L.

Table 10--Product classification sample: Currie Coulee North, Dry Fork East, Dry Fork West, Wet Park (1983)[1]

Product	Length	Small-end diameter range	Average diameter: Small-end	Average diameter: Large-end	Volume: Per piece	Value f.o.b. mill: Per piece	Value f.o.b. mill: Per ft^3	Sample size
	Feet	Inches	Inches	Inches	Ft^3	Dollars	Dollars	Pieces
Post	6.5	1.5-2.5	1.8	2.2	0.14	0.00	0.00	5
Post	6.5	3.5-4.5	3.9	4.9	.69	.52	.75	5
Pole	17.0	1.5-2.5	1.9	2.9	.56	.00	0.00	10
Pole	17.0	2.5-3.5	3.0	4.0	1.16	1.25	1.08	0
Lath log	8.5	4.0-5.0	4.6	5.2	1.12	.75	.67	14
Total								34

[1]Product size classifications and values were provided by operators. Averages were based on a random sample of products in the field (or estimated when not available). Volume was computed from Smalian's formula: V = ((b + t)/2) X L.

Table 11--Product classification sample: Ballard Hill North (1983)[1]

Product	Length	Small-end diameter range	Average diameter: Small-end	Average diameter: Large-end	Volume: Per piece	Value f.o.b. mill: Per piece	Value f.o.b. mill: Per ft^3
	Feet	Inches	Inches	Inches	Ft^3	Dollars	Dollars
Tree length	34.0	1.5-2.5	2.0	4.0	1.85	1.25	0.68
Sawlog	25.0	5.5-6.5	6.0	7.6	6.39	4.95	.77

[1]Product size classifications and values were provided by operators. Averages were based on a random sample of products in the field (or estimated when not available). Volume was computed from Smalian's formula: V = ((b + t)/2) X L.

Table 12--Product classification sample: South Flat (1983)[1]

Product	Length	Small-end diameter range	Average diameter: Small-end	Average diameter: Large-end	Volume: Per piece	Value f.o.b. mill: Per piece	Value f.o.b. mill: Per ft^3
	Feet	Inches	Inches	Inches	Ft^3	Dollars	Dollars
Post	5.5	3.5-6.5	5.0	5.3	0.80	0.43	0.54
Prop	10.0	2.2-3.8	3.0	3.6	0.60	0.50	.83
Pole	12.5	4.0-5.0	4.5	5.3	1.65	0.70	.42
Pole	16.5	3.0-4.0	3.5	4.5	1.46	1.21	.83
Pole	20.5	3.0-4.0	3.5	4.8	1.97	1.40	.71
Houselog	16.5	5.5-	6.0	7.0	3.86	3.30	.85
Firewood	16.5	5.5-	6.0	7.0	3.86	2.14	.55

[1]Product size classifications and values were provided by operators. Averages were based on a random sample of products in the field (or estimated when not available). Volume was computed from Smalian's formula: $V = ((b + t)/2) X L$.

Total product value for each treatment subunit was aggregated by combining all reported piece counts and values for all product classifications. The total delivered value was then reduced to deck (roadside or landing) value by deducting a consistent loading and hauling allowance of $0.15 per cubic foot. This allowance represents the approximate average Northern Region cost for sawlog operations. It is applied here only as a consistent standard for deck valuation and is not represented as indicating actual cost.

Table 13 summarizes recovery by consolidated product categories and shows the total deck value for each subunit. For all 25 subunits, the weighted average deck value of products salvaged is $0.70 per cubic foot. Subunit averages range from $0.52 to $1.38 per cubic foot.

Product Potential

Although actual recovery is certainly of interest, it conveys only spurious evidence of the stand's true product potential. What the forest manager needs to know is how much product value is potentially available to offset the cost of stand treatment.

To evaluate the product potential of the 25 subunits, we used a methodology that we recently developed in a concurrent study (Hawkins and Schlieter, this proceedings). Each subunit was evaluated to see how much product value could have been generated from the stems actually cut and removed. This stepwise procedure predicted the maximum gross value alternative from all possible combinations of seven specified post and pole products. Gross stand values were reduced to net stand values by applying defect factors. These factors were derived from measured value reductions on five sample stands in our product prediction study--stands which happened to be control areas for five of the units in this study.

Basal area reduction and number of stems 3.0 inches and larger cut and removed had a pronounced effect on predicted product value. These relationships can be seen in tables 14 and 15.

RELATIVE FEASIBILITY OF TREATING STANDS

A prudent forest manager will want to identify those stands and treatments where desired biological responses can be achieved at the least net cost. An analysis of incremental costs and potential product value is useful for estimating probable net costs of (or returns from) stand treatments. In this approach, the cost of felling and slashing is the increment required to achieve the desired treatment. All or some part of this cost increment might be offset by product value. But first the product value must fully absorb an associated cost increment--the cost of product removal.

In some stands, the additional value gained from product recovery may enable the forest manager to increase basal area reduction without any appreciable increase in net treatment cost.

Our analysis shows such incremental costs (table 7), product recovery (table 13), and product potential (table 14) for each subunit. But because the removal costs in our study are grossly exaggerated by silvicultural research requirements (and are not related in any way to predicted product potential), we are not able to present meaningful results in terms of net treatment cost or return. We leave to the practitioner the task of estimating product removal costs founded on more realistic harvesting constraints, along with the final assessment of net results.

We were able to compare costs and opportunities in a general way. Table 14 provides an idea of felling and slashing costs in relation to significant variables and product recovery opportunities. Treatment costs are listed in ascending order.

Table 13--Summary of products recovered under contractor's salvage option (on a per-acre basis)[1]

Treatment unit and subunit		Products recovered: Posts	Props	Poles	Other	Total pieces	Volume and Value[2]: Cubic feet	Dollars
Rattling Gu	T-1	668	0	0	0	668	476	285
Rattling Gu	T-2	580	0	0	0	580	437	251
Corduroy E	T-1	161	167	484	0	812	666	609
Corduroy E	T-2	0	223	255	0	478	493	419
Corduroy E	T-3	1,134	125	172	79	1,510	1,332	1,440
Corduroy W	T-1	0	344	26	0	369	182	142
Corduroy W	T-2	452	126	144	0	721	562	392
Corduroy N	T-1	Stand did not contain any merchantable products						
Corduroy N	T-2	0	218	31	0	249	137	111
Echo Lake	T-1	87	0	329	0	416	426	428
Echo Lake	T-2	130	1,875	412	0	2,417	854	1,175
Currie N	T-1	Contractor elected not to salvage any products						
Currie N	T-2	Contractor elected not to salvage any products						
Dry Fork E	T-1	Contractor elected not to salvage any products						
Dry Fork E	T-2	0	0	93	0	93	107	100
Dry Fork W	T-1	Contractor elected not to salvage any products						
Dry Fork W	T-2	17	0	311	0	328	372	341
Wet Park	T-1	0	0	33	79	112	127	81
Wet Park	T-2	0	0	72	362	435	490	288
Wet Park	T-3	0	0	152	566	717	809	493
Ballard N	T-1	0	0	584	0	584	1,079	567
Ballard N	T-2	0	0	1,328	232	1,560	3,941	2,220
South Flat	T-1	0	0	696	11	707	1,155	729
South Flat	T-2	0	37	1,117	13	1,167	1,853	1,175
South Flat	T-3	202	188	1,565	47	2,002	2,907	1,694

[1]Products shown are a consolidation of contractor's actual salvage; volumes and values are not indicative of total stand product potential.

[2]Deck value (value f.o.b. plant less average load and haul cost of $0.15 per cubic foot), 1983 prices.

Table 14--Treatment costs and salvage opportunities for subunits, presented in ascending order of felling and slashing cost (on a per-acre basis)

Treatment unit and subunit		Basal area reduction	Stems <3 inches cut and removed	Cost to fell and slash	Predicted product value[1]
		Percent	No.	- - - - - Dollars	- - - -
Corduroy Cr E	T-1	35	676	266	467
Corduroy Cr N	T-2	66	656	296	307
Corduroy Cr N	T-1	32	0	317	0
Ballard Hill N	T-1	31	815	409	816
Rattling Gu	T-2	48	468	409	562
Rattling Gu	T-1	39	468	429	506
Corduroy Cr W	T-1	34	328	470	181
Dry Fork E	T-1	57	475	491	196
Ballard Hill N	T-2	83	2,085	531	3,279
Corduroy Cr E	T-2	65	1,208	562	1,264
Wet Park	T-1	78	1,441	572	1,090
Currie Coulee N	T-1	48	600	653	459
Dry Fork W	T-1	42	212	677	89
Currie Coulee N	T-2	81	1,110	714	820
Echo Lake	T-1	58	951	756	760
Corduroy Cr E	T-3	100	1,620	869	2,140
Corduroy Cr W	T-2	60	1,112	869	966
South Flat	T-1	42	757	959	395
Dry Fork W	T-2	78	566	982	228
Dry Fork E	T-2	77	1,034	1,125	473
South Flat	T-2	71	1,271	1,204	915
Wet Park	T-2	88	1,887	1,243	1,936
Echo Lake	T-2	79	1,443	1,278	1,149
South Flat	T-3	100	1,125	1,635	894
Wet Park	T-3	100	1,925	2,670	1,871

[1]1984 value f.o.b. manufacturing plant, based on Hawkins and Schlieter, this proceedings.

Percentage of basal area reduction and number of stems 3.0 inches and larger cut and removed are also shown to give an idea of the relative effects of these variables on cutting costs. Predicted product value is included to illustrate the level of salvage opportunity available. Table 15 shows the same information grouped by target basal area reduction subunits (33 percent, 66 percent, and clearcut).

The relative feasibility of treating stands seems to depend a great deal on product potential and market demand. Our results suggest that stands with larger proportions of trees over 3.0 inches, while having higher total treatment costs, often would show more favorable net results than stands composed of smaller trees. This is obviously because such stands tend to yield more product value with which to cover or offset treatment costs.

Thus, when there is a strong local market demand for recoverable products, the feasibility of treating stands appears to increase relative to increases in the number and average size of stems larger than 3.0 inches (relative to predicted product potential). In the absence of strong market demand, the cost-effective treatments seem to be in stands composed of smaller trees. Simply stated, as trees get bigger the cutting cost goes up, but so does the product value.

SUBJECTIVE ANALYSIS

Our frequent monitoring of work in progress during this study enables us to explain some of the study results with a reasonable degree of confidence.

Operator Efficiency

It was apparent that the contractor's experience, skill, organization, and motivation had more bearing on productivity and cost than did the harvesting system and equipment used. For example, contractors for the Corduroy and Rattling Gulch units were more productive using efficient hand-labor systems than were those on Wet Park and South Flat using a crawler tractor and wheel skidder operated by less organized crews. Use of the tree shear was especially detrimental to cutting cost in the Wet Park clearcut.

Salvage Intensity

The intensity of product salvage and extent of manufacture have a direct effect on both cutting and removal costs. This was evidenced by relatively high costs at Echo Lake T-2, Corduroy Creek East T-3, and South Flat T-1, 2, and 3, where utilization efforts were quite intensive. But at Ballard Hill North T-2, where salvage value was highest of all, costs were actually less; this was because nearly all material was marketed at the landing in tree-length decks, thus saving the costs of measuring, limbing, bucking, sorting, and piling products. Lower costs were also experienced at Currie Coulee North, Dry Fork East T-1, and Dry Fork West T-1, where no salvage attempt was made. The lowest of all total costs was at Corduroy North T-1, where the trees were so small that there was neither a salvage effort nor any requirement to remove material from the unit.

Basal Area Reduction

The amount of basal area removed obviously influenced the cost of felling and slashing, as well as the cost of removing cut trees 3.0 inches and larger. This observation was corroborated by both multiple- and simple-regression analyses. Basal area reduction also appeared to correlate well with predicted product value, although this premise was not tested statistically.

Depending on preharvest stand density and d.b.h., the basal area reduction targets resulted in a wide range of residual stem spacings. On the partial-cut subunits, these ranged from 4.0 feet for Corduroy North T-1 to 17.5 feet for Rattling Gulch T-2.

Residual stem spacing appeared to have a dichotomous effect on cost. While closer spacings obviously resulted in fewer trees to cut (and remove where required), they simultaneously had a deleterious effect on production and cost. This was because of a more constant concern for leave-tree selection and protection. The contractor at Currie Coulee North, Wet Park, and the Dry Fork units attempted (without proven success) to address this problem in part by premarking the leave trees.

Close residual spacings affected operators, especially when they were using cable winching systems for required removal. Residual spacings ranging from 5.5 to 6.5 feet at T-1 units such as Dry Fork East and West, Currie Coulee North, South Flat, and Ballard Hill North so inhibited production that the contractors eventually abandoned cable winching in favor of hand-dragging to the unit boundaries for subsequent piling or machine forwarding.

In this study, product-length hand-labor systems seemed to be the more productive alternative for treatments with closely spaced residual stands.

Stand Density and Tree Size

We believed that dense stands of small trees would be more costly to treat than more open stands of larger trees. Subjective analysis could not confirm this any more than did the statistical analyses.

We observed that cutting and slashing trees smaller than 3.0 inches accounted for far less of the total cutting cost than treatment of trees 3.0 inches and larger. This can be explained in part by the highly productive nature of "mowing down" dense stands of small trees with a chainsaw, unimpeded by concerns such as leave-tree selection, directional felling, product salvage, and stem removal. In this study, the cost of

Table 15--Treatment costs and salvage opportunities, grouped by treatment specification (on a per-acre basis)

Treatment unit and subunit	Basal area reduction	Stems <3 inches cut and removed	Cost to fell and slash	Predicted product value[1]
	Percent	No.	Dollars	
T-1 Subunits 33 Percent Target Basal Area Reduction				
Corduroy Cr East	35	676	266	467
Corduroy Cr North	32	0	317	0
Ballard Hill North	31	815	409	816
Rattling Gulch	39	468	429	506
Corduroy Cr West	34	328	470	181
Dry Fork East	57	475	491	196
Wet Park	78	1,441	572	1,090
Currie Coulee North	48	600	653	459
Dry Fork West	42	212	677	89
Echo Lake	58	951	756	760
South Flat	42	757	959	395
T-2 Subunits 66 Percent Target Basal Area Reduction				
Corduroy Cr North	66	656	296	307
Rattling Gulch	48	468	409	562
Ballard Hill North	83	2,085	531	3,279
Corduroy Cr East	65	1,208	562	1,264
Currie Coulee North	81	1,110	714	820
Corduroy Cr West	60	1,112	869	966
Dry Fork West	78	566	982	228
Dry Fork East	77	1,034	1,125	473
South Flat	71	1,271	1,204	915
Wet Park	88	1,887	1,243	1,936
Echo Lake	79	1,443	1,278	1,149
T-3 Subunits Clearcut				
Corduroy Cr East	100	1,620	869	2,140
South Flat	100	1,125	1,635	894
Wet Park	100	1,925	2,670	1,871

[1]1984 value f.o.b. manufacturing plant, based on Hawkins and Schlieter, this proceedings.

cutting 3.0-inch and larger trees included the efforts of optional product manufacture as well as concerns for subsequent required removal. These factors contributed to increased cost.

Thus, once again the evidence seemed to confirm that the number of cut trees 3.0 inches and larger was a more valid indicator of treatment cost than was preharvest density, total stems cut, or average d.b.h.--at least when product recovery was anticipated. For example, Corduroy North T-2 had a preharvest density of 9,400 stems per acre. Average d.b.h. was 2.0 inches with 72 percent of the stems in the 1- and 2-inch classes. Sharply decreasing numbers of stems were in the 3- to 6-inch d.b.h. classes. Basal area was reduced 66 percent and a total of 8,214 stems per acre were cut. But only 656 of the trees cut per acre were 3.0 inches or larger. Felling and slashing cost in this unit was $296 per acre, next to the lowest of all 25 subunits in the study.

Compare this to data for Corduroy East T-1, which had a preharvest density of only 2,875 stems per acre. D.b.h. was considerably larger, averaging 3.7 inches with some stems as large as 8 inches. Basal area was reduced only 35 percent and a total of only 1,784 stems per acre were cut. But the number of cut trees 3.0 inches and larger (676 per acre) and the felling and slashing cost ($266 per acre) were both roughly comparable to Corduroy North T-2 costs.

This contention is further supported by data for Corduroy North T-1, a high-density stand with no trees larger than 3.0 inches. This was among the least costly stands treated.

At first glance, Echo Lake data apparently defy our theory. However, the higher cutting cost in this dense stand of small trees was clearly attributable to intensive manufacture of salvaged products as well as an extraordinary quality of workmanship. Ballard Hill North, with a large number of stems over 3.0 inches and relatively low costs, also seems to defy our logic. But low costs were achieved largely by lack of product manufacture (as noted previously) and by sacrificing job quality.

At the opposite end of this spectrum is Rattling Gulch, an open stand approaching a 5.0-inch average d.b.h. with very few small trees and only 468 cut trees per acre which were 3.0 inches or larger. A few trees were as large as 10 inches d.b.h. Cutting costs again ranked among the lowest. This was mainly because so few trees were cut. Lack of product salvage also improved the cutting cost position by avoiding much of the product manufacturing expense. Salvage was discouraged by large tree size, poor form, and a profusion of limbs, forks, and crooks.

To reiterate our impressions, as cutting costs escalate they tend to trend with the number of stems 3.0 inches and larger and not with total preharvest stems, total stems cut, or average d.b.h. Cases which do not follow this trend can be readily explained by operational inconsistencies such as gross inefficiency, intensity of optional salvage, and quality of workmanship.

Most Cost-Effective Operations

Originally, we anticipated a presentation of operator profit and loss. We planned to show the total costs of cutting and removal, actual product recovery value, and resulting profit or loss for each subunit. In such analysis, subunits showing a profit would indicate stand types, treatments, and harvesting systems where management priorities should be focused. Subunits with slight losses would suggest treatments that might be made for small investments. Large losses would denote submarginal stands, impractical treatments, or unfeasible harvesting systems.

This presentation was not made for two reasons: (1) research requirements that distorted removal cost and (2) inconsistencies of optional salvage efforts. However, the relative profit and loss results (not displayed here) confirmed some of our general impressions. Following are some observations about two of the most cost-effective operations in this study.

Ballard Hill North T-2--This was the most profitable of all operations among the 25 subunits. It had by far the best timber stand in the study.

Tables 1 and 2 show that this 80-year-old stand was growing on an excellent site (index 94), and had the greatest preharvest basal area (357 ft^2/acre). Harvesting removed the largest number of stems (2,085) and cubic feet (6,983) per acre. Trees here were among the largest (3.6-inch average d.b.h.), tallest (47 feet average total height), and best formed in the study. Felling and slashing cost was $531 per acre. More actual product value was recovered ($2,220) and more product was potentially available ($3,279) per acre than in any other subunit (tables 13 and 14).

A tree-length harvesting system was used. Trees were felled, hand-bunched with two or three butts placed in close proximity, winched to the unit boundary, and skidded about 500 feet to a landing. Although a few large trees were limbed and bucked into stud logs and sold on a delivered log basis, most of this material was sold at the landing in tree-length decks with limbs and tops attached. But it was not hauled in this form. The purchaser salvaged and manufactured products at the landing, absorbing the added cost of this work.

This subunit, however, was grossly overcut (83 percent basal area reduction), leave-tree selection was poor, leave-tree damage was excessive, and subsequent blowdown was severe. So some part of the profitability was certainly at the expense of quality.

In spite of the quality problems encountered on this subunit, the study results provide several clear indications regarding treatment opportunities: Highest priority should be given to the best sites. Stands that offer the best combination of density, size, form, and predicted product value should be selected for treatment. Tree-length logging and marketing are probably the most cost-effective combination.

Corduroy Creek East T-1--This was the second most profitable operation. The subunit timber also was among the better timber in the study.

This 85-year-old stand was moderately dense (2,875 stems per acre) and was composed of large (3.7-inch average d.b.h.), well-formed trees. Just 35 percent of the basal area was removed and target residual tree spacing was only 6.5 feet. The one-man hand-labor operation used here was extremely efficient and actual salvage was so intensive that the return substantially exceeded predicted product value. Felling and slashing cost was $266 per acre and predicted product value was $467 per acre.

Study results for this subunit suggest several conclusions: Again, the importance of site index, density, size, form, and predicted product value relative to basal area reduction is evident. These results also suggest that product-length hand-labor operations can be profitable when work is efficiently performed, salvage is intensive, and product marketing is astute.

Comparison of profitability between these two subunits tends to confirm our premise that the harvesting system is not nearly so important as is the operator's experience, organization, motivation, and marketing skill.

FURTHER RESEARCH OPPORTUNITIES

With this base of information to build upon, a series of followup studies could be conducted to experiment further with specified mechanical systems and operating techniques that might improve harvesting productivity. Such studies should be designed to provide a more realistic assessment of incremental costs by conforming more closely to customary product and service contract situations, rather than being bound by silvicultural research constraints. Analysis of comparative costs could be enhanced by requiring more uniform treatment of simulated merchantable material.

OUTLOOK FOR THE FUTURE

The results of this study indicate that salvage of salable products can often be used to offset some of the cost of desired silvicultural treatments in small-stem lodgepole pine. But recovery of products such as posts and poles is seldom great enough to cover all operational costs. Forest managers who prescribe intensive treatments will generally have to subsidize the operator to some extent, depending upon the stand's product potential. To minimize the amount of such subsidies, and to generate positive returns where possible, investments should be concentrated on the best sites and where combinations of tree density, size, and form culminate in the highest predictions of product value.

Low-capital, labor-intensive, family-type operators are the primary resource currently available for harvesting treatments. Limited and unstable markets for small-stem lodgepole pine, coupled with low and fluctuating values, combine to discourage the development of efficient, high-volume, mechanized contractors.

In this study, the better contractors excelled in areas such as crew organization, worker experience, individual motivation, equipment utilization, and marketing ability. These attributes appeared to affect productivity and recovery more than the harvesting system and equipment used. There are opportunities for further cost reduction and revenue generation by refining these basic technical, management, and marketing skills. The most needed impetus can only come from development of stable, high-capacity commodities markets, along with better prices, for small-stem lodgepole pine.

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PRODUCTIVITY OF ALTERNATIVE HARVESTING SYSTEMS IN SMALL TIMBER

Henry L. Goetz

ABSTRACT: Presents productivity and cost data for the felling/bunching, skidding or yarding, and forwarding phases of full-tree harvesting operations on eight thinning and two clearcut units. Trees were felled manually and removed from the woods with grapple-equipped farm tractors, winches, or small skyline yarders. Total stump-to-landing costs ranged from \$0.16 to \$0.80/ft^3 depending on tree size, terrain, harvesting system, and silvicultural prescription.

INTRODUCTION

Full-tree thinning systems have been tested extensively in the Lubrecht Experimental Forest and on neighboring land in western Montana's Blackfoot River Valley since 1975. Full-tree thinning is the term used to describe a system in which trees are felled, piled into bunches, and with limbs and tops attached, removed to a central landing for processing or disposal. The cooperative experiments and demonstration cuttings have involved the Forest Service, U.S. Department of Agriculture (Intermountain Research Station, Northern Region, and Missoula Equipment Development Center), Champion Timberlands, Potter Logging, and the Montana Department of Natural Resources and Conservation. Bill Potter started the initial full-tree system in response to a mountain pine beetle infestation on his ranch. Development and application of the full-tree thinning system on gentle and steep terrain have been described previously (Goetz 1980, 1981, 1982, 1983a, 1983b; Goetz and Maus 1986; Host and Goetz 1983; Maus and Goetz 1986). Copies of the 1986 reports are available from the School of Forestry at the University of Montana in Missoula.

These systems emphasized low-cost portable and versatile equipment that a rancher, woodlot owner, or small contractor could use to thin stands of small timber. The project had two purposes. The first was to demonstrate the many benefits of full-tree thinning, including reduced potential fire and insect damage, easier reentry for future harvests, increased browse for livestock and wildlife, better recreational opportunities, and enhanced esthetic qualities. The second purpose was to determine if some or all of the thinning costs could be offset by the sale of small stems that traditionally have not been marketable. The reports cited previously discuss the variety of markets for material recovered in full-tree thinnings.

This paper has two objectives: (1) to review the methods and machinery used in full-tree harvesting and (2), using data from 10 representative treatment units, to illustrate how terrain, machinery, crew size, and tree size affect productivity and costs. Although much of the work reported was in ponderosa pine, western larch, and Douglas-fir, this information should be generally applicable to stands of small lodgepole pine.

METHODS AND MACHINERY

A full-tree thinning operation consists of at least three and sometimes four phases: felling and bunching, skidding or yarding, forwarding to the landing (on steep terrain), and processing. Because the final products from the 10 treatment units varied significantly, processing productivity and costs could not be directly compared. Therefore, only the first three steps will be presented.

Felling and Bunching

On gentle terrain (slopes <20 percent), a three-person crew, consisting of a sawyer and two stackers, felled and bunched stems less than 5 inches diameter at breast height (d.b.h.). The crews cut the trees as close to the ground as possible. The number of stems per bunch varied with tree size, stand density, and type of skidding or yarding machine used. Although crews can fell and bunch stems larger than 5 inches d.b.h., a small mechanized feller-buncher is two to three times faster than manual methods.

A two-person crew was more efficient than three people on steeper terrain. When thinning smaller trees, the crew piled the trees with butts facing the yarding corridor. The crew did not attempt to pile the larger trees and instead directionally felled them downhill in a herringbone pattern.

Felling and bunching is the most critical phase of the system on both gentle and steep terrain because it dictates the flow in the remaining steps. Poor placement or improper bunch size adversely affects skidding and yarding production.

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Skidding and Yarding

A conventional farm tractor, protected with extra guarding and equipped with a shop-built grapple, was the primary skidding machine used on gentle terrain. Potter designed and built the first versions of the grapple. Plans and specifications for the current model are available from the Equipment Development Center, Forest Service, Missoula, MT. A John Deere Model 440 or 540 grapple skidder was used for larger trees, longer distances, or rougher terrain. In one series of tests, we used the Kolpe Radio-Tir skidding winch to bunch stems for forwarding to the landing with the farm tractor.

On steep terrain, we tested four different yarding machines--two winches and two skyline yarders. The first winch was the Kolpe Radio-Tir. The major advantages of this 330-lb unit were: (1) the radio control feature enabled the operator to control winching from the woods, and (2) the drive rollers of the winch rotated backward while idling and fed the cable out at the rate of a normal walk. The major disadvantage of the unit was the low maximum line pull (1,700 lb) generated by the 6-hp engine. To overcome this lack of power, we also tested a tractor-mounted winch to yard bunches of small trees on short, steep pitches less than 200 ft long. Such winches are available in a range of sizes that fit tractors with 20 hp or more. They are all driven by the power-take-off shaft of the tractor and carry a variety of cable sizes, depending on the specific model. Although many units do not have some of the desirable features of the radio-controlled winches, they do have sufficient pull to yard larger bunches or even sawlogs. For people with tractors, these winches are much less expensive (costs range from $1,200 to $3,000) than the radio-controlled models.

Normally, a three-person crew was used with the winching systems. One person operated the winch and the other two pulled line, carried skidding pans and nose cones, set chokers, and placed breakaway blocks.

The Missoula Equipment Development Center designed both yarders used in the tests. Each was rigged in a live skyline configuration. The Bitterroot Miniyarder is powered by an 18-hp gasoline engine that develops a maximum line pull of 2,000 lb through a hydrostatic transmission. It has a 17-ft tubular steel A-frame boom and a hydrostatic transmission and can be mounted on either a 3/4-ton truck or small trailer. We used the trailer-mounted version exclusively because of its mobility and ease of setup on ridgetops and narrow roads. Parts and rigging for the machine, including a Christy carriage, cost about $7,500. The skyline drum carries 600 ft of 3/8-inch cable, and the mainline drum has 800 ft of 1/4-inch line.

A three-person crew was used in thinning operations. One person operated the yarder and unhooked incoming turns at the landing. The two people in the woods set chokers, moved the skyline stop, and placed breakaway blocks. For clearcuts, we used only one person in the woods.

We also tested the larger and more expensive Clearwater Yarder in a lodgepole pine thinning and a clearcut to compare production rates with the Bitterroot. This three-drum machine has a 97-hp diesel engine that powers a hydrostatic transmission. The skyline drum holds 800 ft of 1/2-inch line, and the mainline drum has a capacity of 900 ft of 3/8-inch cable with a maximum line pull of 3,500 lb. Line speeds vary from 0 to 1,000 ft/min. The yarding crew consisted of one operator/chaser and two people in the woods for both thinnings and clearcuts.

We used a variety of accessory equipment with the different machines to increase efficiency and production. The most helpful item was the breakaway block, which consists of a sheave block with a spring-loaded keeper over the pulley. The block is equipped with a nylon strap that can be wrapped around a tree for easy placement. When the butt rigging on the line trips the keeper, the line derails from the block, and the turn automatically changes direction. We used this device at the junction of the main and lateral yarding corridors during thinning to minimize damage to the residual trees. Breakaway blocks were also used with nose cones and skidding pans on the Kolpe winch units to prevent hangups. We attached a tieback cable to the carriage stop on the skyline of the yarders. This line stabilized the carriage during lateral yarding and reduced damage to trees adjacent to the main corridor. To overcome profile problems in some of the corridors, we tested the intermediate support model of the Christy carriage. It worked well with both yarders.

Forwarding

On gentle terrain, the tractor moved the bunches directly from the woods to the landing. In some instances, the trees were processed immediately--often full-tree chipped for boiler fuel. In other cases, they were shingle stacked for future processing. Shingle stacking is a cold-decking method in which the drag is heeled with the tops off the ground at a 20- to 30-degree angle and backed into a stack. Succeeding bunches then overlap the previous material, and only the butts of the trees are in contact with the ground. Using this system, the same machine can skid, deck, and feed the chipper (Goetz 1982).

The farm tractor was also the main forwarding unit for the winch systems and the Miniyarder. The Kolpe bunched piles along the main skidway for the tractor. With trees 5 inches d.b.h. and smaller, three winch piles were equivalent to one turn for the tractor. When using the tractor winch, the crew would first yard a series of bunches to the road or skidway. They would then replace the winch with the grapple (a 15-minute operation), and one person would forward while the other two crew members thinned another strip. The farm tractor was ideally suited to move material from the Miniyarder to the landing

Table 1--Unit descriptions

Unit	Species	Terrain	Average stem size	Stems removed per acre	Type of treatment
			Ft^3		
1	Western larch	Gentle	0.8	2,500	Thinning
2	Ponderosa pine	Gentle	1.4	1,888	Thinning
3	Lodgepole pine	Gentle	3.0	1,160	Thinning
4	Ponderosa pine	Gentle	1.2	994	Thinning [1]
5	Douglas-fir	Steep	.7	1,331	Thinning
6	Ponderosa pine	Steep	1.4	866	Thinning
7	Western larch	Steep	.9	1,038	Thinning
8	Lodgepole pine	Steep	8.0	665	Thinning
9	Lodgepole pine	Steep	7.6	626	Clearcut
10	Lodgepole pine	Steep	8.3	659	Clearcut

[1]The dashed line is used in all tables to differentiate between gentle and steep terrain.

because the capacities of the two machines match closely. In addition, the tractor moved the trailer-mounted yarder between settings. With the Clearwater, we used the larger capacity John Deere 440 grapple skidder as the forwarder.

PRODUCTIVITY

Productivity and cost data are based on 10 representative units with different combinations of logging systems, stand conditions, and tree sizes. The units are described briefly in table 1; average stem sizes in cubic feet are for those trees removed from the stand. Units on gentle terrain had slopes less than 20 percent; units on steep terrain had slopes ranging from 25 to 50 percent. The thinned stands had an average residual spacing of 14 by 14 ft or a stand density of about 220 trees per acre. Data from two small clearcuts are included for comparison.

Although stems per hour were used to measure productivity in the field, the data were also converted to cubic feet per crewmember working hour in the productivity tables. During working hours, the crew or machine was engaged in harvesting-related activity, including operational time, equipment downtime, and time spent in associated activity such as changing yarding corridors; this definition excludes unit layout, travel, lunch breaks, and record keeping.

Felling And Bunching

Table 2 summarizes felling and bunching productivity for the 10 units. Generally, cubic foot productivity per person per hour increased consistently as the average tree size increased. Felling and bunching productivity in all cases was lower for comparable tree sizes on steep terrain (units 5-7) because it was more difficult to bunch trees on steeper ground. In units 8-10, the two-person crew made no attempt to bunch the trees because of the steep slopes. However, productivity in cubic feet per person per hour increased dramatically when the average tree contained about 8 ft^3. In addition, as indicated by a comparison of unit 8 with units 9 and 10, treatment differences affected productivity--there was a significant productivity increase in the clearcuts compared to the thinnings. Crew experience and amount of downtime account, in part, for the differences in productivity on units 9 and 10.

Table 2--Felling and bunching production rates

Unit	Crew size	Average stem size	Stems per person per hour	Cubic feet per person per hour
		Ft^3		
1	3	0.8	56	45
2	3	1.4	45	63
3	2	3.0	26	78
4	3	1.2	48	58
5	3	.7	41	29
6	2	1.4	22	31
7	2	.9	48	43
8	2	8.0	12	99
9	2	7.6	20	152
10	2	8.3	29	241

Skidding and Yarding

Table 3 lists the skidding/yarding production rates for the 10 units. Unit 2 was skidded by an inexperienced tractor operator during the winter, which may account for the lower-than-expected production rate (compared to unit 1). Generally, one tractor could always keep up with one thinning

Table 3--Skidding/yarding production rates

Unit	Skidder/yarder	Average distance	Average stem size	Stems per person per hour	Cubic feet per person per hour
		Feet	Ft^3		
1	Tractor	500	0.8	212	170
2	Tractor	500	1.4	118	165
3	Tractor	750	3.0	58	174
4	Kolpe winch	80	1.2	64	77
5	Kolpe winch	150	.7	36	25
6	Tractor winch	125	1.4	48	67
7	Miniyarder	275	.9	51	46
8	Miniyarder	275	8.0	10	78
9	Miniyarder	275	7.6	12	92
10	Clearwater	330	8.3	16	133

crew and, in many instances, it could skid for two crews. Lower productivity in the Kolpe winch plots was at least partially the result of a larger crew size. The impact of tree size is demonstrated by the higher productivity in unit 8 compared to unit 7. Productivity for unit 9 (clearcut) was somewhat higher than that for unit 8 because the two-person crew did not have to yard around residual trees; this difficulty was partially offset by using a three-person crew in unit 8. As expected, the best production rates on steep terrain were achieved with the larger Clearwater Yarder, even though the average yarding distance was longer.

The results for units 7-9 are similar to those from other Miniyarder studies. Lynch (1986) reported production rates of 54 ft^3 per crewmember-hour for a two-person crew salvaging material from a fire-killed stand of lodgepole pine in Colorado. The average piece size was 11.7 ft^3. In Appalachia, a four-person crew averaged 34 ft^3 per productive crewmember-hour yarding fuelwood, averaging 5 ft^3 per piece from a hardwood clearcut (Baumgras and Peters 1985). In Washington, a four-person crew used a Miniyarder to remove red alder from sites being converted to commercial timberland; at an average piece size of 5 ft^3, Brown and Bergvall (1983) expected to produce 50 ft^3 per crewmember-hour on an operational basis.

Forwarding

Table 4 lists forwarding production rates for units 4-10. For units 1-3, forwarding and skidding activity are combined in table 4 because the tractor skidded the bunches of trees directly from the woods to the landing. Grapple-equipped farm tractors forwarded trees on all plots except unit 10, where a John Deere 440 grapple skidder moved material from the Clearwater. In unit 9, the tractor operator also limbed and topped the trees before decking.

Table 4--Forwarding production rates

Unit	Average forwarding distance	Average stem size	Stems per person per hour	Cubic feet per person per hour
	Feet	Ft^3		
4	400	1.2	360	432
5	225	.7	371	260
6	550	1.4	125	175
7	325	.9	168	151
8	700	8.0	116	931
9	100	7.6	118	897
10	250	8.3	203	1,685

Combined Production Rates

In table 5, production rates for felling and bunching, skidding/yarding, and forwarding have been combined for the entire operation from stump to landing. The values for each unit represent the number of stems or cubic feet that were felled and bunched, skidded or yarded, and forwarded to the landing per person per working hour. Although no attempt was made to statistically identify causes of variation between units, some general observations from table 5 should be emphasized:

1. for units 1-3, volumetric production rates increased as the size of the average tree increased, and the productivity for unit 3 would have been substantially greater if the skidding distances had been similar for all units;

2. the volumetric production rate for unit 4 (Kolpe-bunched) was less than that for any of the tractor-skidded units;

Table 5--Combined production rates--stump to landing

Unit	Skidder/yarder	Average stem size	Stems per person per hour	Cubic feet per person per hour
		Ft^3		
1	Tractor	0.8	45	36
2	Tractor	1.4	33	46
3	Tractor	3.0	18	54
4	Kolpe winch	1.2	25	31
5	Kolpe winch	.7	17	12
6	Tractor winch	1.4	13	19
7	Miniyarder	.9	20	18
8	Miniyarder	8.0	6	46
9	Miniyarder	7.6	8	58
10	Clearwater	8.3	10	81

3. even though the forwarding distance in unit 6 was twice as long as in unit 5, the productivity of the tractor winch was greater than that of the Kolpe;

4. the difference in production rates between the plots thinned with the Miniyarder was primarily a result of differences in tree size;

5. the productivity differences between thinning units and clearcuts reflected the greater difficulty of yarding at thinned sites as well as the smaller yarding crew used in the clearcuts; and

6. the greater speed and power of the Clearwater are partly responsible for the high production rates for unit 10.

COSTS

The cost-per-cubic-foot calculations are based on the following hourly rates for labor and machinery:

Item	Rate per hour
	(Dollars)
Labor (base = \$6.00; payroll costs = \$2.00; overhead = \$.72)	8.72
Tractors and small skidders	12.00
Tractor winching only	6.00
Kolpe Radio-Tir winch	3.68
Bitterroot Miniyarder	7.00
Clearwater yarder	22.96
Chainsaws	1.50

The rates for labor, tractors/skidders, and chainsaws are consensus estimates by people closely associated with small-stem harvesting in the Northern Rocky Mountain region. We believe these figures accurately reflect rates currently being paid by post/pole operators, private nonindustrial landowners, and small contractors. The labor rate is constant because crewmembers typically rotate jobs frequently during an operation. Obviously, these rates would not apply to a highly capitalized, production-oriented, corporate woods operation. These costs reflect the fact that most landowners and small contractors operate their own equipment, perform higher-than-average preventive maintenance, do many of their own repairs, and depreciate the machinery over a long time period.

The rates for the Kolpe winch, Miniyarder, and Clearwater were calculated as indicated in the appendix. Because the Clearwater Yarder is not commercially available, the costs are based on a comparable machine--the trailer-mounted Christy Small Wood Yarder.

Table 6 summarizes the costs of felling and bunching, skidding/yarding, and forwarding for the 10 units. The total costs are for those three phases only and, with the exception of unit 9, do not include limbing, bucking, and processing at the landing. The costs reflect working hours as defined previously; they do not include operating overhead or a margin for profit and risk.

Data in table 6 demonstrate the effect of harvesting system, tree size, terrain, and silvicultural treatment on small-stem production costs. The costs range from a high of \$0.80/ft^3 for unit 5 where very small stems were bunched with the Kolpe, to a low of \$0.16 for the lodgepole pine clearcut yarded with the Clearwater. The average cost per cubic foot delivered to the landing for all 10 units was \$0.38. Hawkins (this proceedings) determined that the average value of processed lodgepole pine products at the landing

Table 6--Summary of costs per cubic foot for three production phases

Unit	Stem size in cubic feet	Costs per cubic foot: Felling and bunching	Skidding/ yarding	Forwarding	Total
		Dollars			
1	0.8	0.20	0.12	0	0.32
2	1.4	.15	.13	0	.28
3	3.0	.12	.12	0	.24
4	1.2	.16	.13	0.05	.34
5	.7	.32	.40	.08	.80
6	1.4	.30	.16	.11	.57
7	.9	.23	.24	.14	.61
8	8.0	.10	.15	.02	.27
9	7.6	.06	.13	.02	.21
10	8.3	.04	.11	.01	.16

was $\$0.76/ft^3$. Even if a generous amount is allowed for processing, operating overhead, and profit and risk, many of these systems should produce small lodgepole pine roundwood products at a profitable rate.

CONCLUSIONS

Based on the Lubrecht studies, a number of conclusions can be drawn about full-tree thinning systems, the machinery used, and expected production rates. The successful application of small-scale systems requires compromise and cooperation among the silviculturist, marking crew, and logger. For example, sale layout must consider the special requirements and limitations of the machinery involved--a form of corridor cutting may be most efficient in many cases. A closely coordinated approach is also necessary in the entire operation from stump to landing.

The various skidding and yarding machines all functioned well and had a minimum of downtime. It is important for the operators to fully understand the power limitations of the machinery and to develop operating techniques based on finesse rather than horsepower. The simple operation and easy maintenance of these small machines enhance their suitability for landowners and part-time contractors. The use of accessory equipment such as breakaway blocks, nose cones, skyline tiebacks, and intermediate supports is critical to efficient use of the cable yarding units.

Production rates will vary with size of timber, size of crew, terrain, silvicultural prescription, and type of machinery used. However, the most important factors are the determination, innovation, initiative, and flexibility of the crew. The potential profitability of any of these systems is limited by the crew as well as by the particular combination of machines used.

Production costs per cubic foot depend on tree size. In general, the larger the average stem, the lower the production costs. For similar-sized material on gentle terrain, direct skidding from the woods appears to be more efficient than prebunching with a winch. For the same size trees, production costs for winches and small yarders on steep terrain are about twice those of ground-skidding systems on gentle terrain. As expected, costs are higher for thinning units than for clearcuts.

Although current values for hogfuel, firewood, and pulpwood may not always be sufficient to pay the entire cost of a thinning operation for some species, many of these systems should be economically feasible for small lodgepole pine roundwood products.

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Appendix: Machinery Cost Estimates

Item	Machine[1] Kolpe	Miniyarder	Christy
Assumptions:			
Initial cost, fully rigged	$8,000	$16,500	$69,500
Equipment life, years	5	5	8
Machine salvage value, percent	0	20	20
Depreciation, dollars per year	$1,600	$2,640	$7,400
Scheduled hours annually	1,200	1,200	1,200
Maintenance and repairs	50 percent of depreciation		
Taxes, insurance, and interest	20 percent of average annual investment		
Fixed costs--dollars per scheduled hour			
Depreciation	$ 1.33	$ 2.20	$ 6.17
Taxes, insurance, and interest	.80	1.87	8.02
Total fixed costs	$ 2.13	$ 4.07	$ 14.19
Operating costs--dollars per scheduled hour			
Maintenance and repairs	$ 0.67	$ 1.10	$ 3.08
Fuel	.19	.50	1.83
Oil, filters, lube	.03	.10	.37
Wire rope--two sets per year for Kolpe and Miniyarder, one for Christy	.24	.61	2.87
Miscellaneous	.42	.62	.62
Total operating costs	$ 1.55	$ 2.93	$ 8.77
Total costs	$ 3.68	$ 7.00	$22.96

[1] The initial cost of the Christy yarder includes a talkie-tooter type communication system. Inexpensive, voice-actuated, FM radios are included in the miscellaneous category for the Miniyarder.

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MECHANIZED SYSTEMS FOR HARVESTING SMALL-STEM LODGEPOLE PINE IN MOUNTAINOUS TERRAIN

Michael J. Gonsior and John M. Mandzak

ABSTRACT: A study employing a Timbco feller-buncher showed that the advantages of mechanization could be readily extended into steep terrain that adjoins gentle terrain or is otherwise replete with large landings. However, much mountainous terrain, characterized by narrow, tortuous roads incised in steep slopes, presents obstacles to complete ground-based mechanization that are yet to be overcome. The Timbco's performance seemed to be affected more by stand density and utilization specifications than by topography.

INTRODUCTION AND PURPOSE

Lodgepole pine has peculiarities that can significantly influence harvesting and utilization development options. Among the most obvious characteristics are its normally small diameter, intermediate branchiness, thin bark, and generally favorable wood quality and utility for studs, roundwood products, pulp chips, and composition board.

Lodgepole pine tends to have a wide habitat distribution. Much of its range is on flat-to-rolling, frost-pocket lowlands with few impediments to mechanized harvesting and transport. It also occurs quite extensively on high-elevation plateaus and steep slopes with limited or no road access. Thus, lodgepole stands occur in areas that may be restricted to snow-free harvesting seasons because of steep slopes and poor road access, as well as areas that can be harvested relatively easily all year.

The silvicultural potential of lodgepole pine depends substantially on harvesting and utilization options, both for existing stands and for development and management of productive replacement stands. In many areas of its range, lodgepole pine has potential for producing an acceptable and profitable timber crop. Natural regeneration is often easily obtained. Precommercial thinning is often required to avoid early stand stagnation and encourage production of stems sufficiently large to increase stand values and reduce harvesting costs. However, the generally modest annual stand volume increments dictate that investments be constrained at a low level.

Small lodgepole pine trees are somewhat unusual in that, depending on stand density and other factors, they may be of relatively high value for specialty products such as fenceposts, fence rails, and tree stakes. However, markets for such products are small in comparison with the available resource (Barger and Fiedler 1982); and for potentially large-volume markets (such as pulp, fiberboard, or energy production) small lodgepole has little or no advantage over other species. The harvesting cost per unit volume rises as tree size diminishes for lodgepole as for other species; and the large-volume markets generally can attract sufficient supplies of larger, lower cost material (Gonsior and Johnson 1985; Mandzak and others 1983).

Solutions to small-tree harvesting problems require a focus on relatively local conditions. An understanding is required not only of the nature of the available timber resource, but also of the local operating environment. Terrain, climate, the currently available harvesting equipment and how it may be employed, and the actual and potential markets for various products that might be produced must be evaluated.

There are two complementary methods for evaluating alternative solutions for a local harvesting problem. Equipment and technique demonstrations can be effective, particularly when harvesting and product requirements seem to be well understood. Data collection and modeling concurrent with harvesting trials also are useful for objective analysis, especially if the data can be used to evaluate a wider array of alternative harvesting schemes. For example, feller-buncher and skidding production data may be equally useful for evaluation of in-woods chipping and roundwood production schemes.

Mechanization has been an important factor in reducing the cost of harvesting small timber, thus enhancing opportunities for its utilization in high-volume markets (Gonsior and Johnson 1985). However, full mechanization may not be practical if capital is limited, if the markets

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require small volumes, or if work is too sporadic to accommodate a capital-intensive approach.

Until recently, mechanized felling and bunching has been restricted to relatively gentle terrain due to equipment design limitations. However, recent innovations have extended feller-buncher capabilities to relatively steep slopes. One such innovation, the Timbco feller-buncher, was a key element in a study we conducted in a variety of stand and terrain situations in western Montana. Our study was designed to meet four objectives:

1. Evaluate the potential of ground-based, mechanized, multiproduct harvesting systems incorporating a Timbco feller-buncher for steep terrain.
2. Determine the safe operating limits of the Timbco regarding tree size, slope, and ground conditions.
3. Determine operating rates and productivity of production system components as functions of slope, tree size, and other variables.
4. Develop models to predict performance in situations other than those directly observed.

This paper presents and discusses some of our study results that pertain to small-stem lodgepole pine stands. In addition to information on the performance of the Timbco, results from associated studies of mechanized delimbing, debarking, and chipping operations are provided. The reader should find these results and associated discussions useful in deciding where such systems might be used, as well as for predicting performance and assessing financial feasibility.

TIMBCO PERFORMANCE

The Timbco is a tracked feller-buncher designed to operate in steep terrain. Its cab and boom mount can be leveled on slopes up to 27 degrees, or about 50 percent.

The Timbco in our study was monitored in 26 cutting units at five locations during the 6 months from August 1984 to February 1985. The Timbco operators tallied all trees cut, total operating time, and unscheduled downtime (UDT) due to equipment breakdowns or other causes, day by day and unit by unit. We employed observers to acquire detailed time and motion information.

Availability and Utility

The study period spanned 184 calendar days. The Timbco operated during at least part of 89 of these days, 5 of which were on weekends. Subtracting weekends and holidays, there were 122 scheduled workdays during the study, so the Timbco's gross availability was about 48 percent (89/184) based on total calendar days, or about 73 percent (89/122) based on scheduled workdays. Among the reasons for lost workdays were mechanical problems (for example, 2 days were lost due to engine failure requiring field overhaul, and a week was lost due to fuel pump failure) and weather (it was too dangerous for outdoor work due to stormy conditions, or the fuel became so viscous that the engine would not run).

For the 89 days during which the Timbco operated, operating periods ranged from 0.5 to 22.5 hours per workday, averaging about 8 hours. Operators recorded only about 50 hours as UDT, a little more than 7 percent of their total workday time. However, the time and motion studies--which accounted for about half the total hours recorded by the operators--showed that nearly 20 percent of the time was UDT, as shown in figure 1. Of course, it is possible that the operators and the time and motion study monitors disagreed regarding what was or was not UDT.

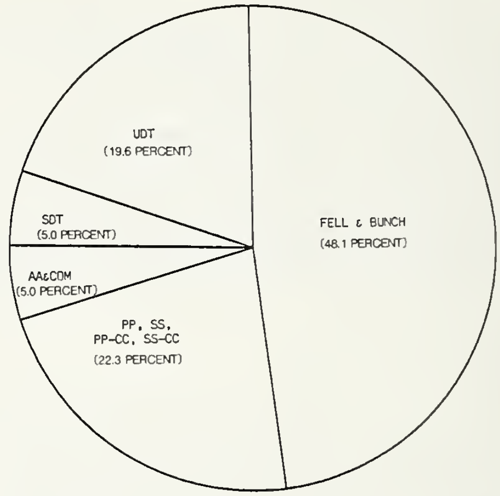


Figure 1--Timbco activity distribution (percent of observed time excluding lunch periods) for entire study. UDT=unscheduled downtime; SDT= scheduled downtime; AA=ancillary activities; COM=commuting; PP=position-to-position moves; SS=strip-to-strip moves; PP-CC=position-to-position moves, including cutting and carrying one or more trees during moving process; SS-CC=strip-to-strip moves, including cutting and carrying one or more trees during moving process; FELL & BUNCH=basic felling and bunching activity while carrier is stationary.

From the time and motion study data, we determined that 70.4 percent of the observed time was spent in the basic productive function: felling and bunching accounted for 48.1 percent of the observed time; moving from position to position (PP, PP-CC) or from strip to strip (SS, SS-CC) accounted for 22.3 percent (fig. 1). (CC means that one or more trees were cut and carried in the process of moving from position to position or from strip to strip.) The remaining 29.6 percent of observed time was recorded as UDT, scheduled downtime for maintenance, refueling, etc. (SDT), commuting between units or between landings and unit interiors (COM), and ancillary activities essential to the work but not directly productive (AA), such as maneuvering down timber or checking for unit boundaries.

Basic Productivity

Figure 2 shows the mean time per tree and number of observations vs. estimated diameter at breast height (d.b.h.) for felling and bunching one tree

at a time, without accumulating. These data represent all the one-tree cycles observed during the study, and they imply a gradual increase in time per tree with increasing d.b.h., up to about 14 inches, beyond which the time per tree increases rapidly with increasing d.b.h.

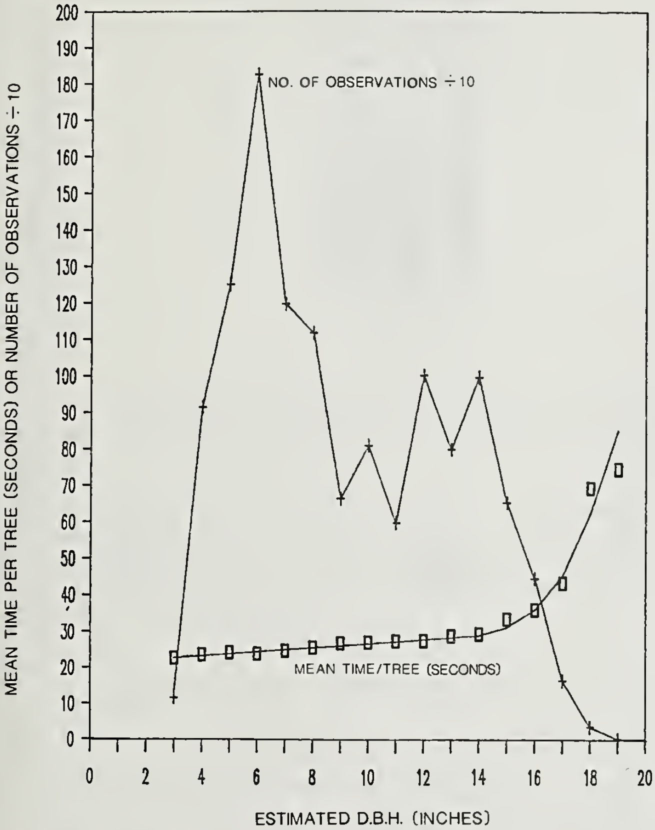


Figure 2--Mean time per tree and number of observations vs. d.b.h., Timbco system, one tree per cycle, for entire study.

To illustrate the effectiveness of accumulating trees before placing them on the ground, figure 3 shows the mean time per tree and number of two-tree cycles observed vs. the mean estimated d.b.h., along with the relationship for one-tree cycles inferred from figure 2. This implies a reduction in mean time per tree in the range of 25 to 30 percent from one-tree cycles (for trees between 3 and 10 inches d.b.h.) when two trees are cut and bunched per cycle. Figure 4 shows further time savings when three and four trees are cut and bunched per cycle. (The abscissas in figures 3 and 4 are actually the rounded means of estimated d.b.h. Usually the estimates of d.b.h. for the trees in multiple-tree cycles varied by no more than an inch or two; so this method of portrayal seems reasonable.)

Effects of Slope, Season, and Utilization

During the summer and early autumn study period, trees as small as 3 inches d.b.h. were utilized. Figure 5A shows the mean time per tree vs. d.b.h. for one-tree cycles, and figure 5B shows activity distributions (as bar charts) for three slope classes during this part of the study. Figure 5 implies decreasing Timbco availability with increasing slope; but no pronounced or consistent effect of slope on basic productivity (mean time per tree) is evident.

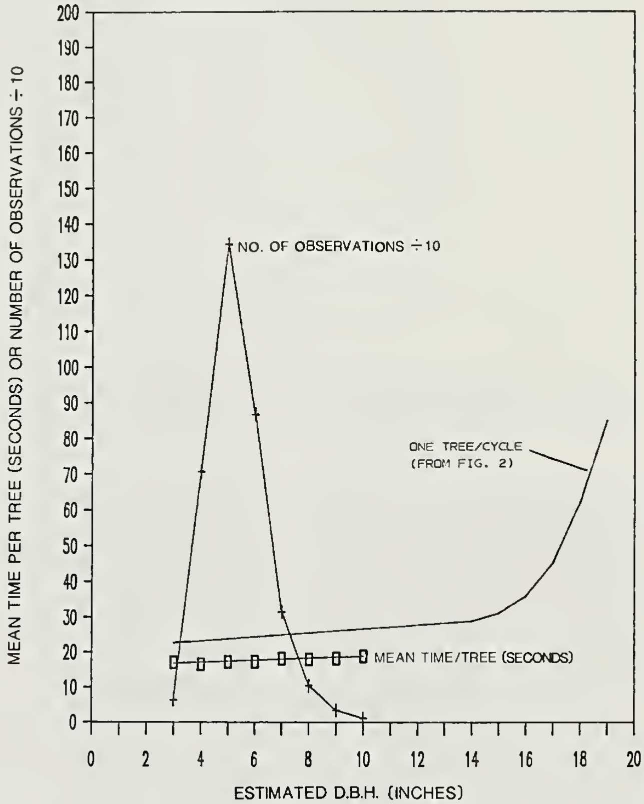


Figure 3--Mean time per tree and number of observations vs. d.b.h., Timbco system, two trees per cycle (compared with one-tree cycles) for entire study.

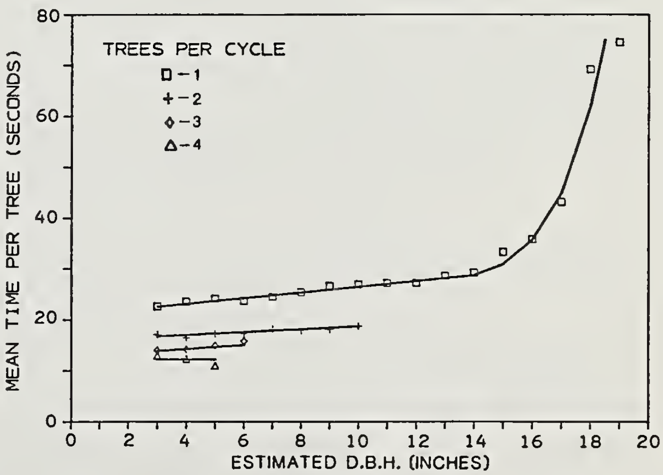


Figure 4--Mean fell and bunch time per tree vs. estimated d.b.h., for one, two, three, and four trees per cycle, Timbco system for entire study.

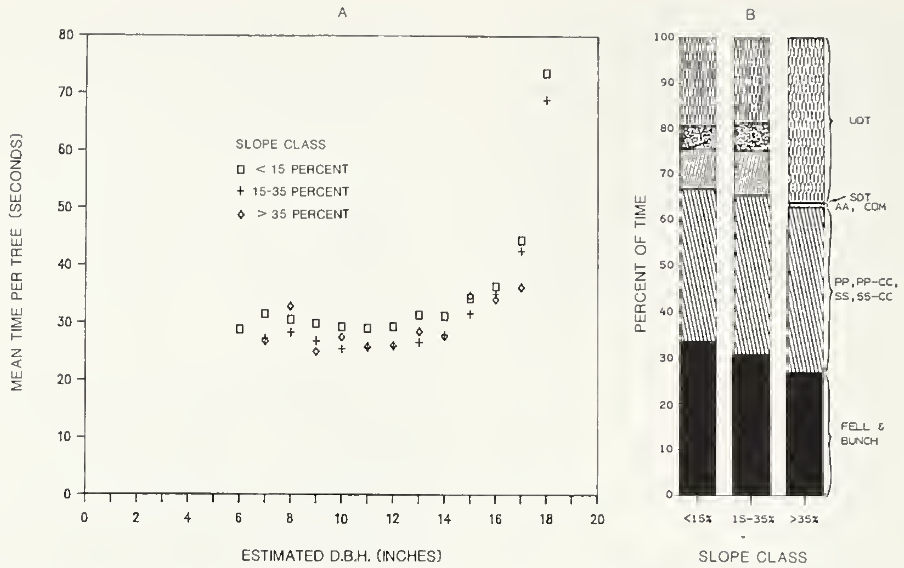


Figure 5--(A) Mean time per tree (single-tree cycles only) vs. d.b.h. and (B) activity distributions (percent of observed time) for three slope classes, Timbco system, close utilization units (8/8-10/15/84).

Figure 6 portrays information for the late autumn and winter part of our study, during which conventional sawtimber utilization was practiced. Note that mean times per tree for one-tree cycles in figure 6A are only slightly higher than in figure 5A, indicating that basic productivity was not affected appreciably or consistently by utilization standard, season, or slope. However, a comparison of the activity distributions in figure 6B with those in figure 5B shows considerable differences, with a much higher proportion of time spent for position-to-position and strip-to-strip moving relative to fell and bunch time in figure 6B. This is attributed to the need to move more frequently and longer distances to reach the larger, more widely spaced sawtimber trees when conventional utilization is practiced.

Comparison of figures 5B and 6B also indicates that Timbco availability was reduced during the conventional utilization period, perhaps due more to the adverse late autumn and winter weather conditions than to the utilization specifications.

BLACK CAT STAND AND TERRAIN CHARACTERISTICS

The stands in an area called Black Cat were more nearly stereotypical small-stem lodgepole pine than any others logged during our study. The Black Cat area lies about 13 air miles northwest of Missoula, MT. Two units, designated 25-84-2 and 25-84-3, were logged at this location. Unit 25-84-2 is about 44 acres, ranging in elevation from 5,550 to 5,750 feet. About

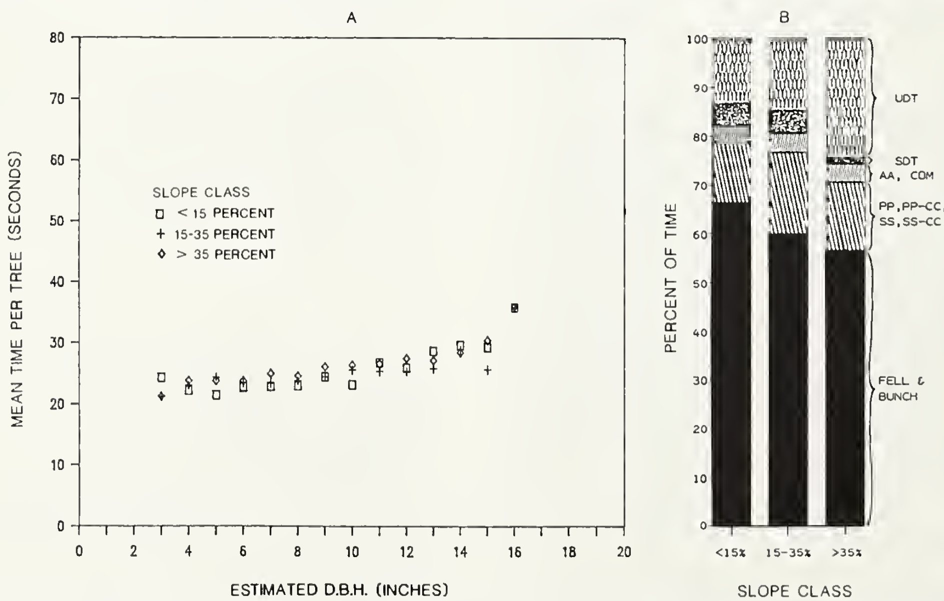


Figure 6--(A) Mean time per tree (single-tree cycles only) vs. d.b.h. and (B) activity distributions (percent of observed time) for three slope classes, Timbco system, conventional utilization units (10/15/84-2/7/85).

Table 1--Total stems per acre, 4 inches d.b.h. and larger, Black Cat Unit 25-84-2

D.b.h.	Douglas-fir	Western larch	Lodgepole pine	True fir	Total
4	4.8	49.9	161.2	0.0	215.9
6	14.5	20.4	114.7	0.0	149.6
8	0.0	10.0	57.5	2.4	69.9
10	4.3	4.4	29.4	0.0	38.1
12	3.0	0.0	5.2	0.0	8.2
14	0.8	0.8	0.0	0.0	1.6
16	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0
22	0.0	0.6	0.0	0.0	0.6
24	0.0	0.3	0.0	0.0	0.3
26	0.0	0.2	0.0	0.0	0.2
28	0.0	0.0	0.0	0.0	0.0
30+	0.0	0.2	0.0	0.0	0.2
	27.4	86.8	368.0	2.4	484.6

Table 2--Total stems per acre, 4 inches d.b.h. and larger, Black Cat Unit 25-84-3

D.b.h.	Douglas-fir	Western larch	Lodgepole pine	True fir	Total
4	0.0	12.7	66.8	0.0	79.5
6	0.0	12.8	87.1	5.0	104.9
8	3.8	6.8	26.3	0.0	36.9
10	2.9	7.9	7.9	0.0	18.7
12	0.0	3.7	0.0	0.0	3.7
14	1.3	1.3	0.0	0.0	2.6
16	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0
30+	0.0	0.0	0.0	0.0	0.0
	8.0	45.2	188.1	5.0	246.3

80 percent of it is in the slope range of 15 to 25 percent. Another 10 percent of this unit is in the slope range of 10 to 15 percent; the remainder is in the range of 25 to 30 percent. Its aspect is dominantly southern. Table 1 is the stand table for Unit 25-84-2 based on pretreatment inventory on 11 variable radius plots.

Unit 25-84-3 lies just downslope from Unit 25-84-2. It is about 18 acres, ranging in elevation from 5,350 to 5,550 feet. Nearly 85 percent of this unit is in the slope range of 15 to 20 percent, and the remainder is in the range of 10 to 15 percent. Its aspect is southern. Table 2 is the stand table for Unit 25-84-3 based on pretreatment inventory on six variable-radius plots.

The logging prescription might be termed a seed-tree cutting, as about four western larch trees per acre were designated to be left in each unit; but, from a practical standpoint, these units were virtually clearcut.

Figure 7 shows the similarity between tree size distributions in the Black Cat units on the basis of d.b.h. estimates made during the time and motion study. (About half of the total stems cut in these units are represented.) Table 3 further compares the stands, showing that stand density in Unit 25-84-2 was about twice that in Unit 25-84-3.

It is reasonable to conclude that Units 25-84-2 and 25-84-3 were alike in most respects, with the exception of stand density.

Table 3--Statistics based on preharvest inventory, Black Cat Units 25-84-2 and 25-84-3.

Unit	Stand density	Volume	Basal area	Net volume
	Stems/ acre[1]	Ft^3/ acre	Ft^2/ acre	Bd ft/ acre
25-84-2	484.6	2,686.9	135.7	6,146.7
25-84-3	246.3	1,479.5	71.8	3,103.7

[1]4 inches d.b.h. and larger.

TIMBCO PERFORMANCE AT BLACK CAT

One of our primary interests in analyzing Black Cat data was to determine whether and to what extent the aforementioned difference in stand density affected the Timbco's performance.

Operators' records showed that the Timbco spent about 15.75 days or 166 hours in Unit 25-84-2 to fell and bunch 17,080 trees. On average, therefore, the mean total workday length was about 10.5 hours and mean production rate averaged about 1,085 trees per day or 103 trees per hour.

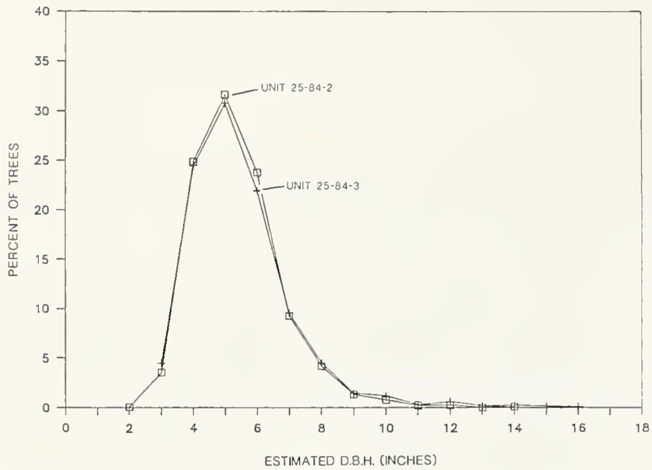


Figure 7--Tree d.b.h. distributions, Black Cat Units 25-84-2 and 25-84-3 (based on time and motion study estimates).

In Unit 25-84-3, about 4.75 days or 47 hours were required to fell and bunch 4,170 trees. Thus, the mean workday length in this unit was about 9.9 hours, and mean production rate was about 880 trees per day or 89 trees per hour.

Therefore, not only was the daily productivity greater in Unit 25-84-2--in part due to longer average workday lengths--but hourly productivity was also about 16 percent higher in Unit 25-84-2 than in Unit 25-84-3.

Time and Motion Study Results

Time and motion observations at Black Cat accounted for about 94 hours and nearly 11,000 trees distributed uniformly over the entire Timbco operating period. Figure 8 shows the distribution of the Timbco's time by activities, based on these observations; and, compared with figure 1, it shows somewhat greater availability and utility than the study average.

Average results such as shown in figures 1 and 8, however, fail to reflect the variations that occur in logging operations. For example, figure 9A shows the daily activity distributions at Black Cat, as well as unit and study summaries. (Note that the bar chart labeled "ALL BLACK CAT" at the extreme right in figure 9A corresponds exactly with the pie chart of figure 8.) Thus, observations over brief periods may be misleading; and it may be necessary to study a logging system over extended periods to obtain an accurate portrayal of its performance characteristics.

Figure 9B shows the percentages of total time and trees tallied by the Timbco operators that were accounted for by the time and motion study monitors, which may be used as a basis for assessing confidence in the corresponding results in figure 9A.

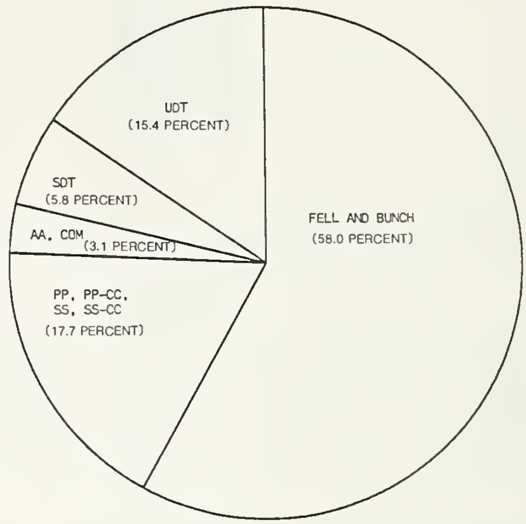
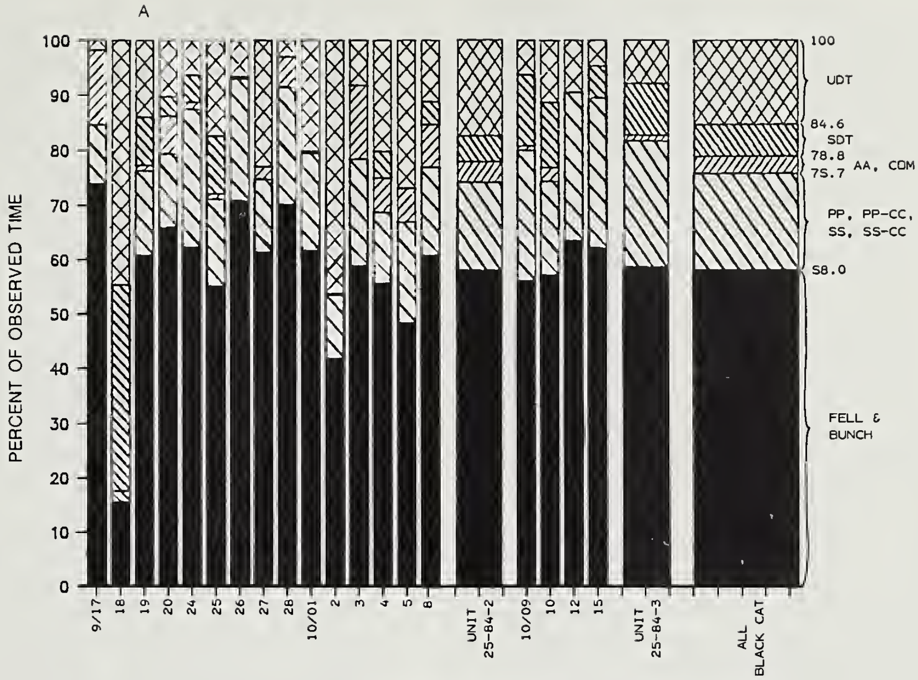


Figure 8--Timbco activity distribution (percent of observed time excluding lunch periods) at Black Cat.

About 93 percent of the observed trees were cut during the 58 percent of time labeled FELL and BUNCH in figures 8 and 9A, and the remaining trees were cut during the operations labeled PP-CC or SS-CC. Of the trees cut during the fell and bunch operation, about 30 percent were cut in one-tree cycles, about 50 percent in two-tree cycles, and the rest in three- or four-tree cycles. Mean times per tree for one-, two-, three-, and four-tree cycles were 24.1, 17.1, 14.2, and 11.7 seconds, respectively.

Figure 4 fairly represents the average basic productivity at Black Cat. Mean time per tree was about 18.5 seconds. Thus, out of an hour, 0.58 x 3,600 = 2,088 seconds were spent in the basic felling and bunching operation, yielding 2,088 seconds ÷ 18.5 seconds per tree ≅ 113 trees attributable to the basic fell and bunch activity. In addition, 7 percent of the trees were cut during the PP-CC and SS-CC operations, for a total of 113 ÷ 0.93 = 121.5 trees per hour. This is appreciably greater than the average of about 100 trees per hour shown by the operators' records; and it is consistent with the discrepancy shown in figure 9B--that the time and motion study accounted for only 44 percent of the total time, but 51.4 percent of the trees, tallied by the operators. It is not clear whether the operators' gross records contained errors, or if there was bias in the time and motion study causing an overestimate of Timbco availability or utility.



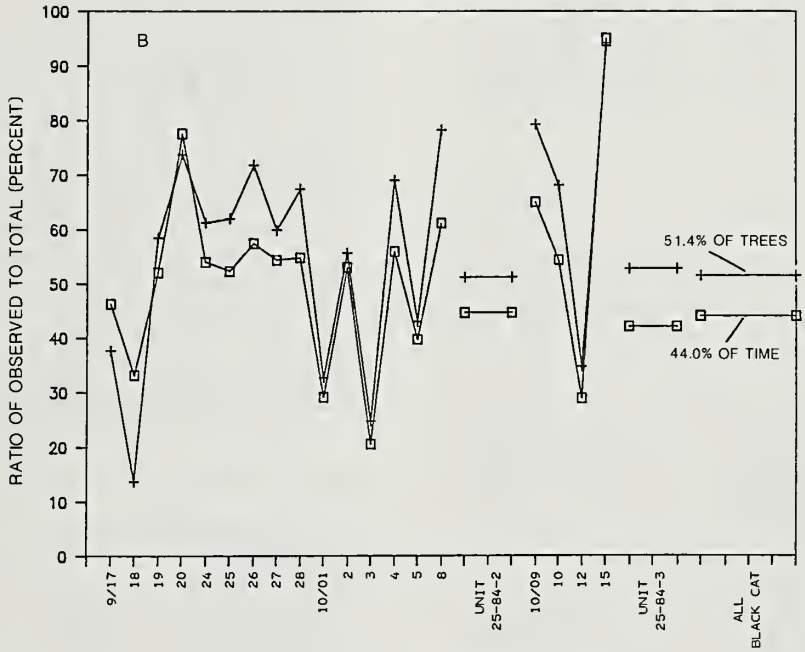


Figure 9--(A) Timbco activity distributions (percent of observed time excluding lunch periods) and (B) ratios of observed-to-total time and trees at Black Cat, day by day, unit by unit, and overall.

Figure 9A shows 17.5 percent UDT in Unit 25-84-2, but only about 8 percent UDT in Unit 25-84-3. Likewise, Timbco utilization was lower in Unit 25-84-2 (about 74 percent) than in Unit 25-84-3 (about 82 percent). However, the proportion of time spent in the fell and bunch activity was almost the same in each unit (a little under 58 percent in Unit 25-84-2 and a little over 58 percent in Unit 25-84-3). Obviously, a considerably greater proportion of time was spent in position-to-position (PP, PP-CC) and strip-to-strip (SS, SS-CC) moves in Unit 25-84-3 (about 23 percent of total time, or about 28 percent of basic productive time) than in Unit 25-84-2 (about 16 percent of total time, or about 22 percent of basic productive time).

The proportion of trees cut in single-tree cycles was lower in Unit 25-84-2 (about 27 percent) than in Unit 25-84-3 (about 38 percent) (fig. 10). Correspondingly, there were more multiple-tree cycles in Unit 25-84-2 (about 53 percent of trees cut in two-tree cycles and about 20 percent cut in three- or four-tree cycles) than in Unit 25-84-3 (about 44 percent of trees cut in two-tree cycles and about 18 percent cut in three- or four-tree cycles).

Basic productivity was also somewhat better in Unit 25-84-2 than in Unit 25-84-3, for which no explanation is apparent. In Unit 25-84-2, the mean times per tree were 23.3, 16.7, 14, and 11.4 seconds in one-, two-, three-, and four-tree cycles, respectively; and the mean value for the unit was about 17.9 seconds per tree. In Unit 25-84-3, the mean times per tree were 26.5, 18.6, 14.8, and 13.9 seconds in one-, two-, three-, and four-tree cycles, respectively; and the unit mean value was about 20.9 seconds per tree.

To summarize, in Unit 25-84-2, nearly 58 percent of the time was spent in the basic fell and bunch operation, during which the mean time per tree was about 17.9 seconds; therefore, there were $0.58(3{,}600)/17.9 \cong 117$ trees cut each hour during this portion of time. In addition, 6 percent of the trees were cut during PP-CC and SS-CC activities, for a total production rate of $117 \div 0.94 = 124.5$ trees per hour.

In Unit 25-84-3, about 58.5 percent of the time was spent in the basic fell and bunch operation, during which the mean time per tree was about 20.9 seconds; therefore, there were $0.585(3{,}600)/20.9 \cong 101$ trees cut each hour during this portion of time. In addition, 9 percent of the trees were cut during PP-CC and SS-CC activities, for a total overall production rate of $101 \div 0.91 = 111$ trees per hour.

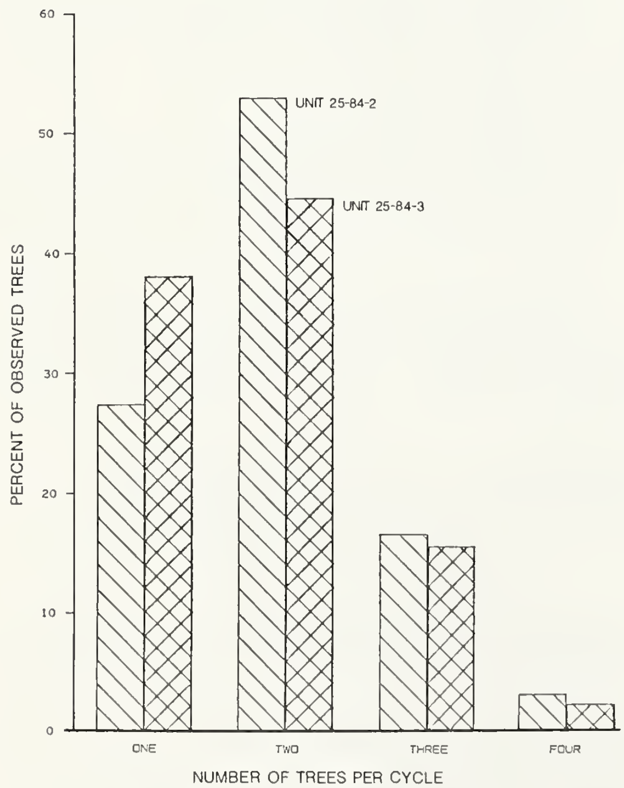


Figure 10--Percent of observed trees cut in one-, two-, three-, and four-tree cycles, Black Cat Units 25-84-2 and 25-84-3.

It is difficult to rationalize why UDT should have been different in one unit than in another. If UDT had been the same in each unit, then the proportion of time attributable to the basic fell and bunch operation would have been lower in Unit 25-84-3 than in Unit 25-84-2. For example, given about 75 percent utilization, the fell and bunch operations would have occupied about $58/74 \times 75\% \cong 59$ percent of total time in Unit 25-84-2, but only about $58.5/82 \times 75\% \cong 53.5$ percent of total time in Unit 25-84-3. Correspondingly, the production rate would have been $[0.59(3{,}600)/17.9] \div 0.94 \cong 126$ trees per hour in Unit 25-84-2, but it would have been only $[0.535(3{,}600)/ 20.9] \div 0.91 \cong 101$ trees per hour in Unit 25-84-3. So we conclude that the production rate in Unit 25-84-2 would have been nearly 25 percent greater than that in Unit 25-84-3, other things being equal; and we attribute this mainly to the difference in stand density.

What about stands without the larger Douglas-fir and western larch trees that were in the Black Cat stands? Considering only multiple-stem cycles (two-, three-, and four-tree cycles) the mean fell and bunch time was a little more than 16 seconds per tree. If 58 percent of the time still was spent in the basic fell and bunch operation, and if we could count on only 5 percent of trees being cut and carried in conjunction with PP-CC and SS-CC operations, then a production rate of about $[0.58(3{,}600)/16] \div 0.95 \cong 137$ trees per hour might be expected. (Indeed, production rates at Black Cat averaged 130 trees per hour during 2 days, based on operators' records.) With nominal workday lengths of 10 hours (as tallied at Black Cat), the daily production rate would be about 1,370 trees. In even denser stands with smaller mean diameters, it seems reasonable to expect daily production rates of at least 1,500 trees per day. However, the reader should be cautious about such speculations without confirming observations.

SKIDDING AND PROCESSING AT BLACK CAT

A Hahn Harvester system, supplied by grapple skidders and assisted by a loader, processed the trees previously felled and bunched by the Timbco. The Hahn Harvester, normally operated by two persons, delimbs and bucks trees up to about 24 inches in diameter. It uses a photocell and associated electro-mechanical devices to measure log lengths. Multiple-stem delimbing and topping can be performed, albeit with some sacrifice in the quality of delimbing. The loader is necessary to remove logs and delimbed boles from the outfeed end of the Hahn and to deck them or load them onto trucks. The infeed boom charges the Hahn with trees and also clears limbs and tops away from the infeed area and piles this debris to the side.

No separate studies of skidding productivity were conducted. Instead, skidding capacity was varied to approximately match the Hahn system's capacity.

Gross Productivity

At Black Cat, the Hahn system operators tallied 19 days or 158 hours (averaging about 8.3 hours per day) to process about 19,640 trees, for a mean gross production rate of about 1,035 trees per day or 124 trees per hour. For Unit 25-84-2, 15 days or 128 hours (8.5 hours per day) were required to process 15,720 trees (about 1,050 trees per day or 123 trees per hour). For Unit 25-84-3, 4 days or 30 hours (7.5 hours per day) were required to process 3,920 trees (about 980 trees per day or 131 trees per hour).

Seven hours of UDT were recorded by the operators, all of which occurred while processing trees from Unit 25-84-2. On the basis of "net" hours (excluding UDT) the production rates in Units 25-84-2 and 25-84-3 were virtually identical. Thus, because tree size distributions in the two units were essentially identical, there is no reason to distinguish between these units with respect to processing with the Hahn system.

Time and Motion Study Results

The time and motion studies accounted for about 89 hours and 10,670 trees, or over half the totals recorded by the Hahn system operators. Figure 11 shows that nearly one-fourth (23.4 percent) of the observed time was lost due to UDT. A little over half (52 percent) of the observed time was spent in the basic processing function (PROC = single-tree processing cycles and MPROC = multiple-tree processing cycles). Of the remaining time, about half (13.3 percent of observed time) was attributable to ancillary activities (AA), mainly slash or debris clearing and piling by the infeed operator. A small amount (3.1 percent of observed time) was spent for maintenance and other SDT, and the rest (8.2 percent of observed time) was attributable mainly to delays caused by running out of trees and waiting for the skidders to deliver more (DEL-OT).

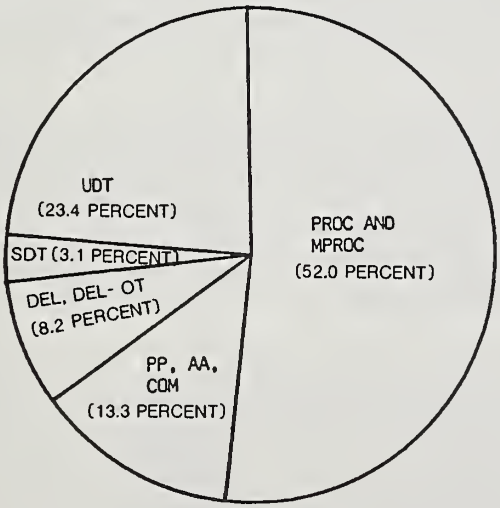


Figure 11--Hahn Harvester activity distribution (percent of observed time excluding lunch periods) at Black Cat. DEL-OT=delays due to being out of trees; DEL=other delays; PROC=single-tree processing cycles; MPROC=multiple-tree processing cycles.

During the 52 percent of time spent on PROC and MPROC, about 24 percent of the trees were processed in single-tree cycles--yielding about one-half sawlog per tree on average--and requiring a mean of about 36 seconds per tree. The remaining trees were processed in multiple-stem cycles, with an average of about 3.3 trees per cycle and a mean time of about 9.2 seconds per tree. Virtually no sawlogs were produced in multiple-stem cycles. Table 4 shows the proportion of trees and the mean times per tree vs. the number of trees per cycle for multiple-tree cycles only; and figure 12 shows the effect of mean d.b.h. on mean time per tree, for both single- and multiple-stem cycles (up to five stems per cycle).

Table 4--Percent of trees and mean time per tree vs. number of trees per cycle, multiple-tree cycles only, Hahn System, Black Cat Units

Number of trees/cycle	Percent of trees	Mean time per tree
		seconds
2	16.5	14.1
3	19.0	10.1
4	16.5	8.1
5	12.0	6.6
6	8.5	5.4
7	3.0	5.0
8	0.5	4.4
Overall[1]		
3.3	76.0	9.2

[1]Note that 24 percent of the trees were processed in single-tree cycles. The results shown here are for the remaining 76 percent of trees processed in multiple-tree cycles.

Figure 12 indicates a rising mean time per tree with increasing d.b.h., especially pronounced for one-tree cycles. Much of this increase for one-tree cycles can be attributed to an increase in the mean number of sawlogs per tree with increasing d.b.h. Measurement and bucking of sawlogs requires more time than mere delimbing and topping of pulp boles, because of the need for careful length measurements and adjustments. Figure 13 shows the relationship between sawlog-to-stem ratio and d.b.h. for the trees at Black Cat, which mimics the mean time per tree vs. d.b.h. relationship for one-stem cycles shown in figure 12.

A mean time of 15.65 seconds per tree was determined from the time and motion study data, resulting in a production rate of $3,600 \div 15.65 \cong 230$ trees per productive hour; but since only 52 percent of the time was spent in PROC and MPROC, the estimate of gross productivity is only about 120 trees per hour--nearly the same as the production rate of 124 trees per hour based on the operators' records.

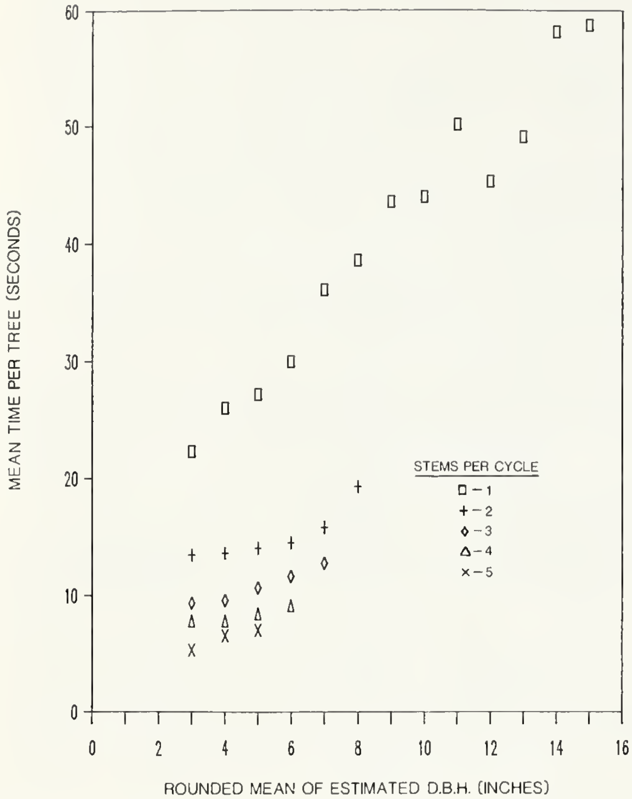


Figure 12--Mean time per tree vs. d.b.h., Hahn system, single- and multiple-stem cycles, Black Cat.

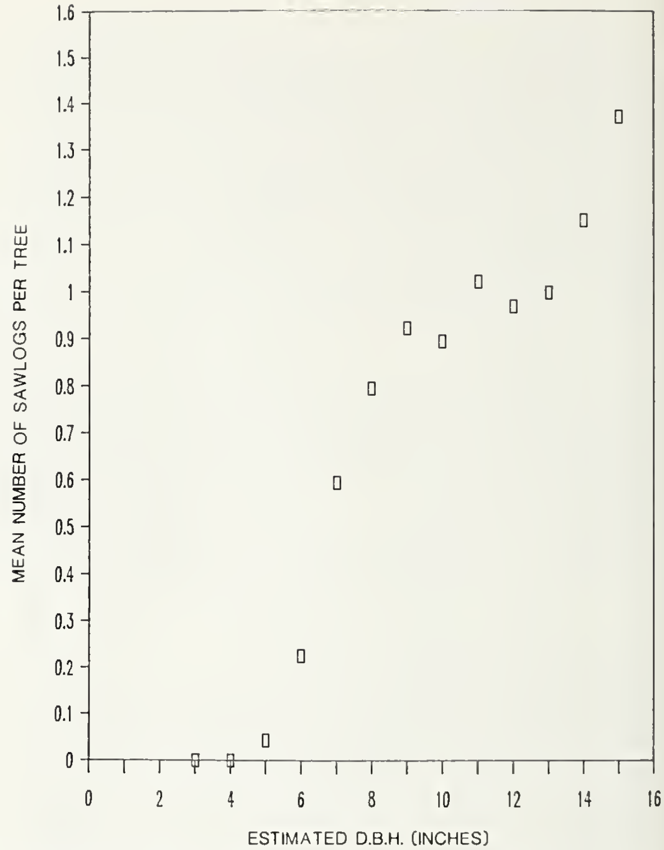


Figure 13--Mean number of sawlogs per tree vs. d.b.h., Hahn system, Black Cat.

Production Compatibility with Timbco

This analysis indicates that the Hahn system's production rate at Black Cat was somewhat greater than that of the Timbco. The discrepancy would have been even greater if skidding productivity had been slightly better (thus reducing or eliminating DEL-OT).

If only small trees were to be processed, without making sawlogs but merely delimbing and topping, then we might expect a mean time per tree about the same as that for multiple-stem cycles--9.2 seconds as derived in table 4. Thus, production rates as high as $3,600 \div 9.2 \cong 390$ trees per productive hour might be expected. Even with only 52 percent of the time spent in the basic activity of PROC and MPROC, this would result in a production rate of about 200 trees per hour or 1,600 trees per 8-hour workday, which is comparable to the previously derived daily production rate that might be expected for the Timbco in denser, smaller stemmed stands.

The Timbco could be operated at night; but skidding after dark is probably inadvisable from a safety standpoint, especially in steep terrain. Thus, production compatibility between the Hahn and Timbco systems seems reasonably good; and it appears that perfect compatibility is achievable--at least theoretically--by working the Timbco extra hours.

Material Balance

Gross production records at Black Cat showed an output of about 20,380 pulp boles and 2,470 sawlogs from 19,640 trees. The net sawlog volume was about 164,000 bd ft (Scribner) entailing 39 logging truck loads, for mean values of 63.3 logs or 4.21 thousand bd ft per truck load. The weight of these logs was 1,079 tons, averaging 27.67 tons per truck load and about 2.29 logs per ton.

The discrepancy between the Hahn and Timbco tree tallies of 19,640 and 21,250 trees, respectively, may reflect errors in tree estimates made by the infeed boom operator on the Hahn. When grabbing bunches of small trees, it is difficult to see all of them clearly. In contrast, the other Hahn operator can see the delimbed and topped boles relatively easily.

The ratio of pieces produced (22,850) to stems tallied (19,640) is 1.16 pieces per stem, based on the gross production data. However, from the time and motion study data, a ratio of about 1.09 pieces per stem was calculated, based on observations of nearly 11,000 trees. Thus, if we consider the ratio of 1.09 pieces per stem to be more reliable than 1.16 pieces per stem, we conclude that the Hahn system infeed operators may have underestimated the trees processed. Further, if we consider the estimate of total pieces (sawlogs and pulp boles) to be accurate,

then applying the ratio of 1.09 pieces per tree yields an estimate of the number of trees processed of nearly 21,000 trees--a number reasonably close to the Timbco operators' tally of 21,250 trees.

Of course, if the Hahn system operators' tree tally should have been about 21,000 instead of 19,640, and if their tally of 158 hours is accurate, then the gross production rate was about 133 trees per hour. This is considerably greater than the estimate of 120 trees per hour computed on the basis of the time and motion study results; and it implies bias in the time and motion study, suggesting that availability or utility was actually greater than concluded therefrom. Again, it is not clear whether the major cause of discrepancy was bias in the time and motion study or errors in the operators' records.

PULP BOLE CHIPPING

Our use of the term "pulp bole" is somewhat misleading. An original study objective was to utilize trees down to about 4 inches d.b.h., as well as the tops of larger trees from which sawlogs or plywood peelers were produced. We hoped that the Hahn Harvester could strip enough of the bark from these trees and tops to satisfy pulp chip quality standards--thus the term "pulp boles." Additionally, the limbs and other debris were to have been chipped for hog fuel.

As it turned out, the pulp boles could not be debarked cleanly enough to meet pulp chip standards, so the chips produced from them ended up as hog fuel. Moreover, the difficulties encountered in trying to chip the limbs and other debris were judged insurmountable.

Obviously, it would have been considerably more efficient to bypass the Hahn and chip whole trees, if only hog fuel chips were to be produced. Not only would there have been somewhat greater yield, but the cost of delimbing and topping would have been avoided. Nevertheless, we decided to proceed with the original plans for two reasons: (1) pulp chip quality standards may change in the future, making currently unacceptable chips acceptable and (2) there are circumstances in which chipping may not be desirable or possible, but where hauling of delimbed and topped "pulp boles" might be considered. Thus, information about delimbing and topping small trees was considered of sufficient importance to continue with the operation as originally planned.

The chipping system consisted of a Morbark Model 18 chipper, rubber-tired grapple skidder(s), and several chip vans, tractors, and drivers. Skidder and chip truck capacities were adjusted for reasonable compatibility with chipper productivity. No separate studies of skidder or chip truck productivity were undertaken. However, skidder turns were tallied to permit rough estimates of skidder requirements in other situations.

Gross Productivity

At Black Cat, where the road is relatively steep and winding, only 40-foot vans could be used. (Elsewhere, both 45-foot and 40-foot vans could be used.) Records maintained by the chipper operators showed that 16 workdays totaling about 132 hours (averaging 8.25 hours per workday) were required to chip the estimated 20,380 pulp boles produced by the Hahn system--yielding 127 van loads of chips, for an average of about 1 hour per van load and eight van loads per workday. A total of 3,152 green tons or 1,453 bone-dry units (BDU) were produced, averaging about 24.8 green tons or 11.44 BDU per van load. The mean net time per van load at Black Cat--excluding time spent for adjusting chipper position between vans, waiting for vans to arrive, UDT, SDT, and other matters, but including delays caused by running out of wood while chipping and having to wait for the skidder(s) to deliver more--was about 38.5 minutes, requiring a mean of about nine skidder turns per van load. Thus, less than two-thirds of the total time was attributed to van filling by the operators.

Time and Motion Study Results

Personnel shortages precluded detailed time and motion study of the chipping system at Black Cat. However, results obtained during operations near St. Regis immediately before the Black Cat operations should be applicable. Based on these results, figure 14 shows that about 60 percent of the time was attributable to van filling, of which about one-fourth (14.8 percent of total time) was lost due to delays caused by running out of wood. Net chipping time for 40-foot vans averaged only about one-half hour at St. Regis, and about 32.5 minutes for 45-foot vans (see table 5). If delays caused by running out of wood while chipping are included, the mean filling time for 40-foot vans at St. Regis was about 39.5 minutes, or nearly the same as the 38.5 minutes inferred from the operators' data at Black Cat.

Table 5--Chipping system productivity at St. Regis

Number of van loads observed	Van size	Mean fill time Gross	Net	Mean of skidder turns required per van load
		- - Minutes - -		
42	40-ft (11-12 BDU[1])	39.4	30.2	9.9
20	45-ft (12-13 BDU)	43.6	32.6	10.3

[1]Bone-dry unit (BDU) = 2,400 lb, bone-dry

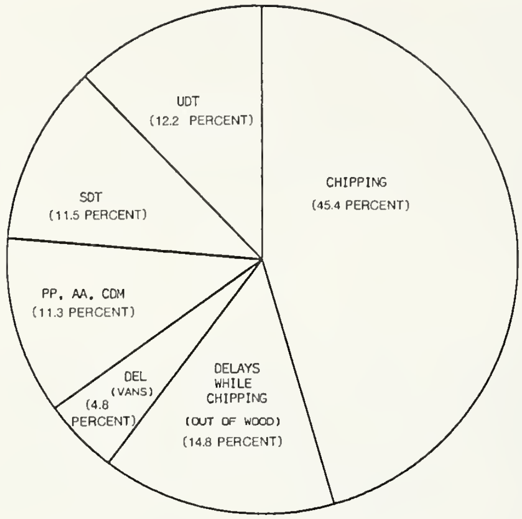


Figure 14--Chipping system activity distribution (percent of observed time excluding lunch periods) at St. Regis. DEL(VANS)=delayed due to being out of vans.

Production Compatibility with Hahn and Timbco Systems

Although the gross production records indicate reasonable compatibility between the chipping system and the Hahn processing system at Black Cat (16 days or 132 hours for chipping versus 19 days or 158 hours for processing), the time and motion study results suggest that the chipping system might be able to match the productivity of up to two Hahn systems in the right circumstances.

This is not to imply that the chipping system was operated inefficiently during our study. Nor do we suggest that skidder or van capacity could be increased to avoid delays without added cost. We merely imply that, if the chipper could be kept operating at its rated capacity, utilization of about 65 percent might reasonably be expected. In an 8-hour day, this would mean about 312 minutes of chipping, or about 10 van loads of chips per day. Had this been possible at Black Cat, the 127 van loads would have been completed in about thirteen 8-hour workdays, or in less than 70 percent of the time required by the Hahn system to process the pulp boles. By operating the chipping system overtime, productivity approaching twice that of the Hahn system would seem to have been readily attainable.

The Hahn system was handling large as well as small trees in our study, and producing sawlogs and plywood peelers in the process. With only small lodgepole stems containing no sawlogs and peelers, the production rates of the Hahn and chipping systems probably would have more nearly matched. However, as discussed earlier, the combination of delimbing and chipping may not be tenable without debarking as well.

The chipping system's productivity of 20,380 pulp boles in 16 days equals about 1,275 boles per day; and with the implied gain of 25 percent deemed possible by eliminating certain delays, a production rate of up to 1,600 boles per day might reasonably be expected. The Timbco should be able to fell and bunch about this many small-stem lodgepole pine trees, depending on stand density. Thus, in a whole-tree chipping operation in dense stands of small trees, there should be reasonably good compatibility between the Timbco and a chipping system of the type described here.

IN-WOODS DEBARKING

Our inability to satisfy pulp chip quality standards heightened our interest in the potential for in-woods debarking. An opportunity arose to study the performance of a Morbark Model 2250 debarker during a brief period of about 15 hours distributed over 4 days in January, 1985.

The debarking system consisted of the debarker, a hydraulic loader, and a grapple skidder. The skidder delivered bunches of whole trees to the infeed end of the debarker and roughly delimbed them with its blade. A sawyer topped the stems and removed any remaining limbs with a chainsaw. The sawyer also bucked the crooked stems into shorter, relatively straight segments when necessary. The limbs and tops were gathered by the grapple skidder and taken to the chipper for conversion into hog fuel. The skidder also occasionally pushed bark away from the debarker into waste piles.

Time and Motion Study Results

Figure 15 shows the proportions of observed time spent by the debarking system in various activities. Availability of the system was high; only 5.4 percent of the time was lost due to UDT, more than half of which was caused by a hose leak on the loader.

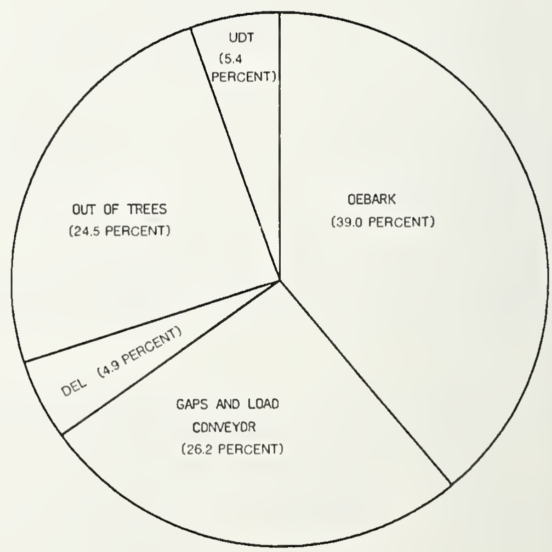


Figure 15--Debarking system activity distribution (percent of observed time excluding lunch periods).

Although availability was relatively high, utilization of the debarker appears low in figure 15. Only 39 percent of the total time (about 41 percent of available time) was spent in the basic debarking function, while another 26.2 percent of total time (27.7 percent of available time) was accounted for by gaps between the stems.

About 1,220 pieces were debarked requiring a mean time of about 17 seconds per piece. Gaps between pieces accounted for about 11.4 seconds per piece, on average. About 5 percent of the gaps, accounting for about 20 percent of gap time, were beyond the control of the debarker operator. These were caused by failure of the loader to supply the infeed conveyor of the debarker. The other 95 percent of gaps, accounting for 80 percent of the gap time (and averaging about 10 seconds per piece) were presumably controllable by the debarker operator.

Of the remaining 29.4 percent of total observed time, most was lost simply because the system was out of trees. The skidder was unable to keep the debarker supplied during about 24.5 percent of total observed time. Another 4.9 percent of the time was accounted for by various other delays--mostly waiting for the sawyer to complete delimbing and bucking tasks before the loader could perform its role.

We expected that feed rate while debarking would be inversely proportional to stem diameter. Thus, lengths and end diameters of the pieces were estimated. Based on these estimates, the mean diameter of each piece was calculated, and the aggregates of times and lengths for all stems within each mean diameter class were used to deduce mean feed rates. Figure 16 shows the relationship between these feed rates (expressed reciprocally in seconds per foot) and mean diameters; and the relationship weakly supports our expectations.

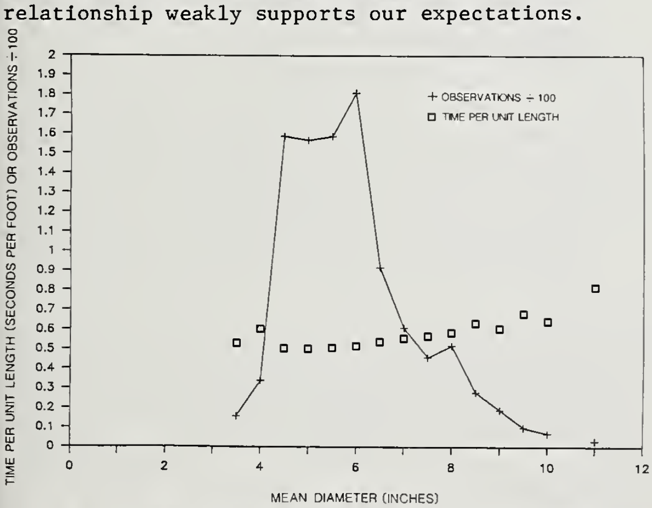


Figure 16--Mean time per unit length and number of observations vs. mean stem diameter for the debarking system.

Excluded from figure 16 are those debarking cycles that contained unusual delays, such as occasional times spent reversing stems to achieve better quality; so this figure should be used for estimation purposes only with caution. Represented in figure 16 are 1,027 stems, or about 84 percent of all the observed stems. Mean stem length was about 30.8 feet and mean debarking time was about 16.5 seconds (or about 0.54 seconds per foot). But mean time for all the observed stems was about 17 seconds. From this it can be inferred that the remaining 16 percent of stems not represented in figure 16 required a mean time of about 19.5 seconds. Thus, if their lengths and diameters were distributed approximately as those represented in figure 16, it may be concluded that these "problem" stems required nearly 20 percent more time for processing.

Production Compatibility with Other Systems

In stereotypical small-stem lodgepole pine stands, where the stems are relatively straight, mean feed rates of at least 2 feet per second should be readily attainable with a debarker of the type described here. If stem lengths (exluding tops) averaged 30 feet, a mean time of 15 seconds per stem would be required. If delays caused by running out of trees and some of the other gaps between stems could be nearly eliminated, thereby increasing effective debarking time to about 65 percent of total time, then at 15 seconds per stem the production rate would be 156 stems per hour, or about 1,250 stems per 8-hour day.

It seems reasonable to expect fairly good compatibility between a debarking system of the type we studied and the other systems described here if operations are in small-stem lodgepole pine stands, and if minor adjustments in workday lengths among the systems are acceptable.

DISCUSSION AND SUMMARY

A major purpose of studies like ours is to provide a basis for predicting systems performance in future circumstances. Unfortunately, circumstances in timber harvesting are seldom repeated, especially in unmanaged forests in mountainous terrain. Also, harvesting equipment is operated by humans whose skills and motivation vary. Consequently, it is difficult to generalize and extrapolate to circumstances beyond those in which a study of this type is conducted.

By some standards, the Black Cat stands highlighted in this report would be considered to be dense and small-stemmed; nevertheless, they were not nearly as dense, nor were the trees as small, as many lodgepole stands. Therefore, while we consider our speculations regarding Timbco performance in other, "more typical" small-stemmed lodgepole stands to be sound, the reader should be cautious and seek numerous sources of information as a basis for predicting outcomes in new situations.

When clearcutting stands denser than Black Cat, it is reasonable to expect Timbco production rates at least as great as those reported here, all else being equal. However, while production rates may increase in terms of trees per unit of time, volumetric production rates may be lower, depending on tree sizes.

For thinning operations, it is considerably more difficult to predict Timbco performance on the

basis of this study's results. No doubt, production rates, in terms of trees harvested per unit time, would have been lower had the Black Cat units been partially cut instead of clearcut. But in stands considerably denser than those at Black Cat, especially if mean tree sizes were smaller, production rates as high as or even higher than those reported here might reasonably be expected in heavy thinnings where residual stand densities are relatively light. Obviously, the lighter the thinning and the denser the residual stand, the lower the expected production rate. Above certain residual stand densities, systems like the Timbco and associated skidders or forwarders cannot be used at all--depending on the degree of stand uniformity required--simply because of inadequate maneuvering room.

Although the Timbco can operate on steep terrain, it may not be able to negotiate road cuts in many situations (for example, it cannot climb vertical rock cuts). Thus, much mountainous terrain accessed by narrow roads incised into steep slopes may not be accessible to the Timbco, even though the terrain itself might be otherwise operable. Also, systems like the Hahn Harvester and Morbark chipper and debarker require sizable landings for efficient operation; so even if the timber can be cut and moved to roadside, mechanized processing and handling may require alternative technologies. Otherwise, it may be necessary to forward the trees significant distances to favorable landing sites.

While we recognize that the primary reason for predicting systems performance is to enable estimation of cost, we leave it to the reader to make such estimates on the basis of chosen assumptions regarding wage rates, equipment ownership and operating costs, and other factors.

Technologies like the Timbco provide the advantages of mechanization in circumstances where harvesting was formerly possible only with less efficient and more hazardous methods; but there are many mountainous areas where obstacles to mechanized ground-based timber harvesting remain to be overcome.

ACKNOWLEDGMENTS

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PREDICTING THE PERFORMANCE OF ALTERNATIVE HARVESTING SYSTEMS IN SMALL TIMBER //

William R. Taylor

ABSTRACT: Discusses a systematic approach for predicting performance of alternative small-timber harvesting equipment and systems and describes the steps necessary to evaluate new equipment or new harvesting methods. Systems analysis and synthesis are required for the prediction of overall productivity and costs. Sensitivity and risk assessment are also addressed.

INTRODUCTION

The problems associated with the timber industry in general, and lodgepole pine in the Rocky Mountain area in particular, significantly impact large portions of our society. The "good stuff" next to the road is gone! Harvesting relatively small timber from steep slopes in very remote areas will likely require new technology or at least significant variations of the more traditional approaches. Each new piece of equipment will generate its own enthusiastic supporters, as well as doubters. Invariably, its success or failure will depend upon its productivity and its associated cost. The problem is that managers generally want to see productivity and cost data before they commit to any new methods and equipment. This frequently requires the use of models to predict the future performance.

SYSTEMS MODELING

Because models are but abstractions of the things they represent, they can take on a variety of forms: pencil and paper calculations, a computer program, a physical likeness, and so forth. Computers are excellent for this type of activity since they can make millions of calculations in seconds in response to changes in input data (Taylor n.d.).

The types of models frequently used to predict performance and cost data for harvesting equipment usually involve a computer. This does not mean that they need be complex to be accurate or effective. A macro-to-micro approach is recommended.

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Sometimes called a "top-down" method, the macro-to-micro approach moves from a general statement of the system to one that provides more and more detail as the model is further developed. The advantage of this approach is that the model provides useful information from its inception without requiring that it be fully developed and completed. In case resource constraints such as limited time or money prohibit further model enhancement, much can usually be learned from the model even though it is not completed in terms of details. For this approach to be successful, it is essential that a "systems approach" be used.

SYSTEM DESIGN

If a model is to accurately predict performance and costs it must give a valid portrayal of what it represents. That is, the system on paper (or in a computer) must behave the same as the equipment in the field. This suggests that before seeking answers on productivity and cost, one should seek a thorough understanding of the problem at hand, the equipment, and how the equipment relates to or impacts other equipment and people. Many models do not work because the analysts do not take the time to really understand the equipment and the environment in which it must operate.

The Operating Environment

Equipment designers generally have a particular environment in mind when they create new machines. Obviously, rubber-tired skidders do not work as well on steep terrain as they do on relatively flat ground. To structure a good model, the analyst must begin with a thorough understanding of the harvesting site and timber characteristics. Factors such as size of the area, slope of the terrain, amount of down timber, top and breast height diameters, heights, species, and count data help define the problem. One excellent method for evaluating new equipment is to identify a cutting unit and its related inventory information from cruise data. Then compare productivity and cost data related to harvesting the cutting unit using the new equipment with that of present or more traditional approaches. This helps establish a benchmark on performance.

Understanding the Equipment

It is impossible to model a piece of equipment without a complete knowledge of how it works. It is important to read the equipment specifications

and operating instructions and talk to those who have operated the equipment. Better yet, acquire field data on productivity and costs from the equipment manufacturer, the Forest Service, or others. Frequently, sales literature will offer a video tape of the equipment operating. If so, get the tape and view it.

The kind of information needed to construct a model includes:

- What does the equipment do (and not do)?
- How does it do it?
- Are there other ways to utilize it?
- What is its production rate?
- What limitations does it have?
- What are the nominal factors influencing performance and their range?
- What operator skill level and training is required?
- What are the initial costs, operating and maintenance costs, and so forth?

With a thorough understanding of the equipment and how it operates, as well as the environment in which it must function, attention must be focused on how this new equipment or method will impact other components of the harvesting system.

Interfacing the Equipment

Frequently in timber harvesting, a machine is significantly impacted by the equipment immediately "upstream" from it, and likewise it affects those operations that follow it. It is common in the logging industry to find equipment idle because it is waiting for another machine to do its job. Also frequently observed is a piece of equipment that is so overloaded that work is queuing up in front of the machine, resulting in a bottleneck in the production process.

These kinds of problems can be avoided (or at least minimized) by examining not just the new piece of equipment but the system in which it must operate. By using a "systems approach" it is possible to balance the production rates of each piece of equipment and increase system productivity.

SYSTEMS MODEL

A typical systems model for timber harvesting is shown in figure 1. Down the left-hand side the main elements of the model are identified as "Inputs" to the model, the "Activities" within harvesting, and the results or "Outputs" from the model.

The Input section basically identifies the model time, cost, and scale factors that are unique to a particular problem. For example, inputs to the Felling activity include the cycle time per zone, number of trees per zone, cost per hour per zone, average tree size and setup time, and cost per zone. This allows a cutting unit to be partitioned into several zones each having unique characteristics. The cycle time represents how long it takes to cut a tree. The user would obviously input different values for a sawyer and a feller-buncher. Building a generalized model allows it to be used for a variety of situations. Similar input data is required for each of the activities of the model.

The timber harvesting process generally follows the sequence shown for activities in figure 1. In some cases a particular activity may be almost

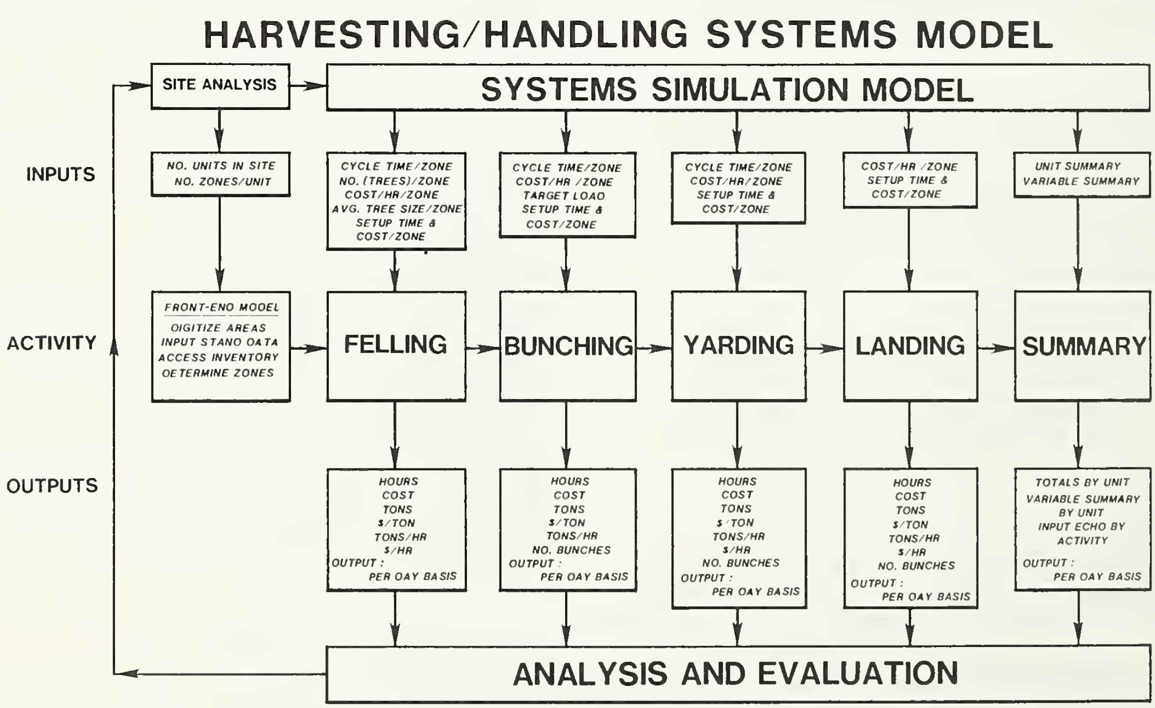

Figure 1--This schematic illustrates a typical systems model for timber harvesting.

nonexistent. For example, when helicopter yarding is involved, there may not be much bunching. However, chokers would be attached to trees and this could easily be handled as a bunching activity. The activity sequence in figure 1 thus does describe most harvesting situations.

The calculations involved for each activity are really rather simple, but they do lead to sound total productivity and cost data. For example, if one knows the number of trees in a zone, the cycle time per tree, and the cost per hour, the product of these terms yields the cost of the activity for that particular zone. This concept will be illustrated further with an example. Outputs from the model provide information regarding costs and productivity. For example, relative to a particular zone of the cutting unit one can determine the time and costs related to an activity along with the cost per ton, dollars per hour, tons (or board feet) per hour, and so forth. These data provide the basis for analyses and evaluations. If the data from each activity are summed from felling through loading, overall site, cutting unit, or zone, analyses can be made. This makes it possible to compare productivity and cost data for a particular site or cutting unit (when one or more of the activities is accomplished with new equipment) with a more established or traditional approach.

An Example

Frequently, one of the major obstacles to using models is the lack of good, accurate input data. The data in figure 2 illustrate how one might develop the "cost per hour" for a piece of equipment such as a feller-buncher.

Machine: feller-buncher
Initial Cost: $150,000 = P
Useful Life: 5 years
Salvage Value After 5 Years: $30,000 = L
Overhaul: $15,000 after 3 years
Interest Rate: 10 percent per year
Operating Costs: $29,000/year (calculated as follows)
(150 days/year)(9 h/day)($20/h) = $27,000/year
plus other miscellaneous costs = $ 2,000/year
Total Annual Operating Costs = $29,000/year

The interest rate of 10 percent is sometimes called a Minimum Attractive Rate of Return and represents a worth of money to the investor. He expects to earn at least 10 percent by investing in this machine. The first step in determining the "cost per hour" is to convert all of the data in figure 2 into an equivalent uniform annual cost. This is done by using interest factors that take into account that money has time value (White and others 1977).

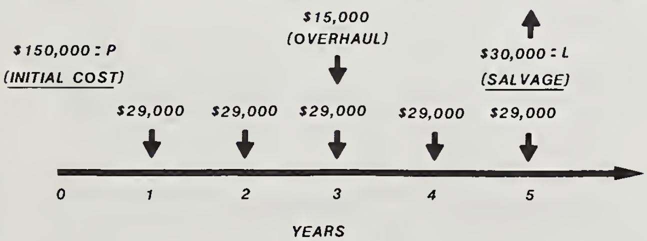

Figure 2--Illustrated are the base cost data needed to calculate the hourly cost of a feller-buncher with a useful life of 5 years. P = initial cost; L = salvage value after 5 years.

Three different interest factors are used in this particular calculation: (1) Capital recovery factor designated (A/P,i,n), (2) Single payment compound amount factor (F/P,i,n), and (3) Sinking fund deposit factor (A/F,i,n). Each of these interest factors is simply an algebraic expression involving the interest rate per period, i, and the number of periods, n. "P" represents a single, lump-sum amount of money at the "present" time, while "F" represents a lump-sum amount of money at some "future" time. When the same amount of money flows each period, it is called a "uniform series" and is designated "A". The interest factors permit the transforming of money at one point in time into an equivalent pattern at a different point in time. For example, the $150,000 initial cost in figure 2 can be transformed into an equivalent amount per year by multiplying it by the capital recovery factor as follows:

$150,000 (A/P,10 percent,5) =
$39,569.62 per year for 5 years.

The algebraic expressions for these interest factors are as follows:

Interest factor	Symbol	Equation
Capital recovery	(A/P,i,n)	$\frac{i(1+i)^n}{(1+i)^n-1}$,
Single payment compound amount	(F/P,i,n)	$(1+i)^n$,
Sinking fund deposit	(A/F,i,n)	$\frac{i}{(1+i)^n-1}$

Each term in the following equation converts an amount from figure 2 into an equivalent annual amount over a 5-year period.

Annual Cost = $150,000 (A/P,10 percent,5) + $29,000
+ $15,000 (F/P,10 percent,2) (A/F, 10 percent, 5)
- $30,000 (A/F,10 percent,5)

Annual Cost = $39,570 + $29,000 + $2,973 - $4,914 = $66,629/year

Hence, the dollar-time scale in figure 2 can be replaced by (is equivalent to) the one in figure 3.

Dividing 150 working days per year into the $66,629 per year yields a cost per day of $444.19 for owning and operating the machine. Dividing 9 hours per day into $444.19 yields $49.35 per hour. This is the number required as input to the model.

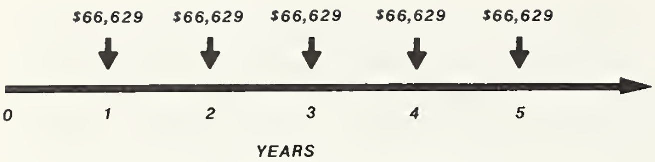

Figure 3--Converting cost data presented in figure 2 to an equivalent uniform annual cost results in the costs shown here.

Obviously, one should include all relevant costs when making these calculations. Costs such as those involved with setup, transportation of the equipment to and from a site, overhead, insurance, and so forth easily could be included.

Now, consider the kind of calculations to be made for each activity in the model. Suppose the feller-buncher was used to harvest a zone within a cutting unit that contains about 300 trees and that the cycle time is 1 minute per tree. Typical cost and productivity calculations are illustrated below:

Cost = (300 trees/zone)(1 min/tree)(1 h/60 min) ($49.35/h).

Cost = $246.75/zone.

Productivity = (300 trees/zone)(1 min/tree) (1 h/60 min).

Productivity = 5 h/zone.

Production Rate = (1 tree/min)(60 min/h) = 60 trees/h.

The calculations are simple with the aid of "dimensional analysis." By simply including the units along with the numbers, one can cancel terms until the desired result is obtained on the units.

SYSTEMS ANALYSIS

A well-constructed model can be extremely useful as a planning tool. One of its primary uses is to analyze the impact of "changes in the input" on the output. For example, suppose that the analyst is not really comfortable with the $20 per hour figure for operating cost. Suppose it is $40 per hour. What effect will this have on the cost of felling per tree? Or, suppose that the cycle time is 2 minutes per tree rather than 1. How will this change the queue of trees in front of bunching or yarding? The ability to play "what if" with a good model allows one to appreciate the risk involved in investing in a new piece of equipment.

In other industries managers frequently require three different scenarios to be presented: (1) the best case, (2) the worst case, and (3) the most probable case. The best case assumes that all costs will turn out to be on the low side and that productivity data will be very high but reasonable. In other words, if everything goes well this analysis would indicate a very optimistic point of view. A worst-case scenario would assume that everything will go poorly and would result in a pessimistic outlook. Thus, the manager has a range from worst to best with the real outcome probably somewhere in between. The most probable scenario presents the most likely values and should be the way the analyst really believes things will occur.

CONCLUSIONS

Unfortunately, investors and managers generally need to know what the future holds before making a decision regarding new equipment or methods for harvesting timber. There never seems to be enough time or information available when contemplating such a decision.

A model for predicting performance of timber harvesting equipment is rather simple. It does not require sophisticated mathematics or complex submodels to obtain good answers. It does require a thorough understanding of the equipment, its environment, and the system in which it is to operate. It also requires sound, accurate input data if the output is to be realistic and meaningful. It is helpful, but not necessary, if the model can be placed in a small computer since this will speed up the calculations and facilitate sensitivity analysis; that is, changing input information describing specific variables to observe effect upon productivity.

Although it will require some thought and time to develop the model, systems analysis works. It is an excellent way to assess risk. (When you think of it, about the only other way is to listen to what you or someone else has learned from past experience.) Using dimensional analysis to assist in determining how to calculate the desired output really simplifies the thought processes and reduces the time required to construct the model. To say that you don't believe in models because you don't believe anyone can predict all of the costs begs the question. We have no choice. The future is where we all will spend our time, and anticipating what is out there is required in some fashion every time we evaluate new equipment. Give modeling a try--you might just get hooked on its simplicity and effectiveness.

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245 A NEW HARVESTING SYSTEM FOR STAGNANT STANDS OF LODGEPOLE PINE //

Richard Karsky

ABSTRACT: The Forest Service would like to reduce the cost of converting large tracts of small-stem, stagnated lodgepole pine stands into more viable commercial timber-producing stands. The wood chunker and the tree harvester described here are being developed to make such conversions cost-effective and to utilize the biomass that is removed. The tree harvester uses a swath mowing concept to cut 300 to 600 trees per hour, which are converted to chunks by the chunkwood chipper.

INTRODUCTION

The Intermountain region of the United States has a significant problem with large tracts of stagnant stands of lodgepole pine. Typically, these stands have such large numbers of stems per acre that their growth has stagnated before the trees are merchantable. In addition to the utilization problem, these stands are vulnerable to fire and insects because the trees are under stress. Treatment by removing the existing trees and establishing more productive stands is too costly because of inefficient harvesting methods for this material and a lack of markets for the resulting biomass.

The Forest Service Missoula Equipment Development Center (MEDC), Missoula, MT, has begun seeking solutions to the problem of recovering and utilizing the biomass from these problem stands in the Intermountain West. Increased demand for fuel wood has created a potential market that opened the door to solving this problem, if cost-effective methods of recovering the available biomass can be found.

A major potential market in this region is the electricity-generating industry. Early discussion with power company personnel has indicated they would prefer an energy wood particle larger than the coventional wood chip. Chunkwood technology may meet this demand. The combination of a tree harvester now in development and a specialized chunkwood processor may make removal operations in stagnant stands more economical and better suited to fuel use.

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WOOD CHUNKER

Development of the wood chunker (fig. 1) is a continuation of wood processing equipment research accomplished by Forest Service personnel at the North Central Forest Experiment Station laboratory at Houghton, MI (Arola and others 1983). "Chunkwood" is the name given the wood particles produced by the chunker--particles that can be several inches long and wide. Chunkwood production offers a number of advantages over production of conventional hog fuel chips. The chunker uses one-third the power per ton of material used by conventional chippers, the larger particles have higher bulk density and more weight per vanload than chips, the larger particles promote increased drying with reduced spontaneous combustion hazard, and fewer fine materials should reduce particulate emissions during burning. Blades on the chunkwood chipper tolerate more trash with less sharpening than conventional chipper blades. In addition, the long particle length parallel to the grain makes chunkwood a potentially suitable material for further mechanical reduction into flakes for waferboard or particleboard products. Particle length parallel to grain can be varied from 1 to 5-1/2 inches.

Figure 1--Wood chunker and loading conveyor.

The prototype chunker is based on the concept of an involuted disc slicer originally conceived by forest engineering project scientists in Houghton, MI (Mattson and others 1985). The

cutter wheel is a 2-inch-thick disc 42 inches in diameter. Detachable blades bent on an 18-inch-diameter radius are mounted perpendicular to the surface of the disc. Either two or three equally spaced blades are used. The leading edge of each blade is set at a greater radial distance from the center of disc than the trailing edge (fig. 2), so the trailing edge curves inward with respect to the leading edge. The blades are tapered so the leading edge projects about 1 inch from the surface of the disc, while the trailing edge projects about 13 inches.

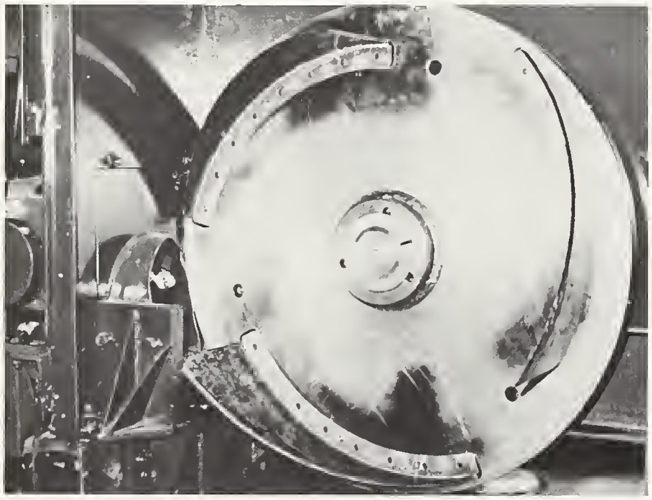

Figure 2--Cutter wheel with rear of cutting blades closer to center of wheel than the forward edge of blade (rotation counterclockwise).

Material to be cut is fed through a rectangular anvil horizontally secured to the infeed frame. The anvil is located near the rim of the disc, but offset from the plane of the disc to match up with the cutting blades. The center of the anvil is positioned slightly to the right of the disc center to obtain the desired entry and exit of the blades. The anvil is contoured to provide slight clearance between it and the blades as the chunks are severed from the workpiece.

Four hydraulically powered feed rollers positioned immediately ahead of the anvil feed material directly into the cutter, then a conveyor moves the chunkwood from under the cutter to a second conveyor. The secondary conveyor loads the material onto a truck (fig. 1). This differs from a conventional chipper operation in that the processed wood is conveyed rather than blown into a chip van. The cutter wheel revolution per minute can be varied, which affects the length of the chunk produced and the rate at which material can be fed into the chipper.

The initial blades were made of 4140 annealed alloy steel. After 6 hours of use they were resharpened because there was about 1/8 inch of wear on the blades starting about 4 inches up from the bottom. The blades were slightly bent from about 4 inches up on the cutting edge diagonally across to the trailing edge of the blade at the disc surface. The blades were replaced with blades made from T-1 steel.

Testing

In October 1985, the machine was demonstrated and tested in the Colville National Forest, WA (Karsky 1986). A load of green logs 8- to 12-inch d.b.h. and material 4- to 6-inch d.b.h. from dry slash piles (about 56 tons of material) were chunked. The machine operated for 7-1/2 hours and used 85 gallons of fuel. The blades were not sharpened and did not bend; however, they did become almost too hot to touch. The cutter wheel was operated at 160 to 250 revolutions per minute, producing an average chunk 2-1/2 to 3-1/2 inches long, parallel to the grain (fig. 3).

Figure 3--Chunks produced by wood chunker. Average thickness is 2-1/2 to 3-1/2 inches.

A two-blade cutter wheel was installed to replace the three-blade wheel. The machine was then operated in the Lubrecht Experimental Forest, MT, in November 1985. The chunks were 3-1/2 to 4-1/2 inches long--an average of 1 to 1-1/2 inches longer than those produced by the three-blade cutter, but shorter than expected.

A series of tests were run in spring of 1986 with different blade offsets or pitches, and different edges on the blades. The offset affects how much closer the rear of the blade is to the center of the cutter wheel than the front point (fig. 2). Three offsets were tried: 0, 2-1/2, and 4 inches. Two edges were tried: a single bevel that has the blade sharpened on one side only, with the sharp edge closest to the anvil; and a double bevel where the blade is sharpened equally on both sides, with the cutting edge in the middle. Each of the offsets and blade edges required different anvils, so these had to be changed when each combination was tried. The main objective of these tests was to improve the feed rate through the machine and to produce longer chunks.

Test Results

The single-bevel knife edge deflected the blade into the anvil when chunking material larger than 6 inches in diameter. Even with the larger offset, the double blade appeared to deflect slightly into the anvil when chunking large-diameter material. This would have to be monitored in future testing. About 52 horsepower was required to cut a green 8-inch-diameter log. Recommendations are to use double-bevel blade edges with either the 2-1/2-inch or 4-inch offset. A maximum average chunk length of 5-1/2 inches could be obtained with the 4-inch offset cutter. With the standard offset of 2-1/2 inches, a maximum average chunk length of 4-1/2 inches could be obtained. Shorter lengths could be obtained by speeding up the cutter wheel. The feed rate using the two-bladed cutter wheel with the 4-inch offset appears to be at least 20 percent greater than the rate using the two-bladed cutter wheel with the standard 2-1/2-inch offset.

Chunking small-diameter wood is a viable alternative to chipping. It offers new opportunities for utilizing small timber and creates a new market for commercial chunking machines. Commercialization of this technology should help utilize currently marginal wood resources, and should contribute to achieving improved stand management in small-stem stagnated stands.

TREE HARVESTER

The basic concept of the tree harvester now under development is similar to that of an agricultural reaper. The concept was developed by the Prince Albert Paper Company, Prince Albert, SK, which operates one machine fabricated to evaluate the concept (fig. 4). The tree harvester is limited to maximum slopes of 15 to 20 percent, but a large part of stagnant lodgepole pine stands are on relatively level ground. The machine functions as a continuously moving feller-buncher, not as a "stop and go" conventional feller-buncher (fig. 5). It mows down trees with a large circular saw while traveling along the periphery of a stand. The harvested trees are accumulated and subsequently unloaded as a bunch, with the butts in line. Its production rate is estimated at 300 to 600 trees per hour, depending on stand density. This is about three times as great as a conventional feller-buncher. Prince Albert Paper Company reports harvest rates of about one-half acre per hour with their machine, called the A line tree swather (Heidersdorf 1982).

Initially, the new tree harvester was to be a purchased machine already in production. The production machine did not materialize, so a contract was negotiated with a firm to build a machine. However, in December 1985, the proposal was withdrawn and MEDC was directed to build the machine.

Seven concepts with many variations were considered and evaluated by MEDC. These concepts included trailer units, two-joint articulation

Figure 4--Prince Albert Paper Company A-line tree harvester.

Figure 5--Multiple stem felling with A-line tree harvester.

schemes, a displaced remote cab, operating the unit in reverse (similar to the Prince Albert Paper Company's model), and extended-wheel arrangements to offset the drive system. A Timberjack 520A rubber-tired skidder-forwarder was purchased as the prime mover for the swather and will be incorporated into the design. The final design will have the frame of the Timberjack 520A extended about 12 feet and offset 4 feet to one side. The saw will be located off to one side, slightly behind the operator. Only one operator will be required to control the harvester. The major components of the tree harvester have been ordered. Fabrication will begin in fall of 1986 with a target completion of the machine in summer of 1987. The machine will be operated at the MEDC test area and any deficiencies discovered after the initial operation will be corrected. The machine will then be shipped to the Colville National Forest in Washington for operational testing.

The MEDC tree harvester will be similar to the Prince Albert A line tree swather. The Prince Albert swather basically consists of a trailer with a side-mounted saw towed behind a Clark 668 skidder (fig. 4). The trailer includes an enclosed cab for the swather operator who controls the trailer's functions. This operator communicates with the skidder driver through a horn-signaling system.

A gooseneck at the front of the trailer is attached to a slide plate on the skidder with a ball-and-socket. This arrangement allows the operator to shift the 36-inch swath width +12 inches.

As the machine travels along the face of the stand, the swather operator moves the trailer in and out and selects the trees to be cut. A compeller or rotating arm aligned with the outer edge of the saw forces the trees either to enter the tree gate to the saw opening or pushes them fully out of the saw's path. The saw blade is flame-cut, 64 inches in diameter, 3/4 inch thick, and rotates at 800 revolutions per minute. Power is supplied to the saw by a hydraulic motor. The saw frame may be hydraulically raised or lowered to control stump height and avoid obstacles.

Once a tree has been cut, its butt is knocked forward by a trip chain mounted behind the saw. Simultaneously, a rotating persuader or "bat" strikes the tree 11 feet up its trunk, clearing the tree's top from the stand and directing it back into the tree basket. When 1 to 2 cords of trees have been collected in the basket, the bunch is dumped to the side away from the stand, clear of the machine's path in subsequent passes.

The machine with the skidder is 60 feet long, weighs 136,700 lb loaded, and has a loaded footprint pressure of 12 psi under the trailer tires. Power for the swather's hydraulic functions is furnished by a 245-hp engine mounted on the trailer. During harvesting, the machine travels at speeds up to 3 mi/h.

The tree harvester should reduce the cost of harvesting small-diameter material for stand treatment. The tree harvester is limited to slopes under 20 percent, but there are many thousands of acres of stagnant stands located on terrain with suitable slopes. Combined with the chunkwood chipper technology, the "swather-chunker" system can efficiently convert small stems into a product suited to fuel or fiber end uses.

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Products, Processes, and Markets

Chaired by: Charles H. Hawkins III

Small lodgepole pine trees have historically found limited markets for posts, poles, rails, and similar products. Volumes of material utilized by these markets today are very small in comparison to the total available resource, although the growth potential in such markets has not been exhaustively explored. An essential key to more extensive management of the small lodgepole pine resource is the identification of new product markets, especially for products or uses that are relatively high-valued. Lodgepole pine has a number of favorable physical characteristics that make it particularly well suited to both roundwood and chip, flake, or fiber products. Information presented in this section discusses product prediction, the current post and pole industry in Montana, and the outlook for other uses.

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PREDICTING PRODUCT POTENTIAL IN SMALL-STEM LODGEPOLE PINE STANDS

Charles H. Hawkins III and Joyce A. Schlieter

ABSTRACT: Managers need a procedure to assess product potential in small-stem stands using conventional stand table or cruise plot information. A system that predicts merchantable length and potential product recovery using diameter at breast height (d.b.h.) and total height for lodgepole pine trees in 3- through 7-inch d.b.h. classes is briefly described. Results of the research include tabled alternative product mix information for representative small-stem lodgepole pine stands, as well as a general computer routine. Users have the options of applying the product information developed for a sample stand that has characteristics similar to the stand they are evaluating, or using the computer routine with stand table or cruise plot data to identify product potential. This paper includes only the tabular results for a single sample stand.

BACKGROUND AND OBJECTIVES

Forest managers in the Rocky Mountain West are faced with a major problem: How can effective multiple-resource management be achieved in stands of small-stem, economically submarginal lodgepole pine? Harvesting merchantable forest products is generally the principal means available to finance work on desired silvicultural and nontimber resource objectives. Consequently, an important management function is to identify merchandising opportunities, alternatives, and values. Specific knowledge of the kinds, quantities, and values of merchantable products that can be recovered from a stand will enhance the management planning process.

Actual product recovery from similar stands is obviously of interest. But such operations may be false indicators of real product potential, because individual operators are strongly influenced by personal preference, equipment limitations, and market constraints. What forest managers need is an effective methodology for predicting total product potential in small-stem stands using conventional stand table or cruise plot information. Also important is the identification of alternative product mixes or combinations and associated values recoverable from a stand.

To satisfy this need, we developed a system that enables managers to accurately predict potential of a stand to produce various combinations of common small-diameter roundwood products. Estimates of the gross product potential are reduced to realistic net estimates based on observed tree defects in the stand.

We hope this methodology will be useful to both land managers and harvesting operators in evaluating economic feasibility. Although many small-stem stands may not generate a profit under any circumstance, the ability to identify product potential and maximize value recovery will tend to reduce the net costs of desired stand treatments.

This paper provides only a capsule description of the methods developed, along with tabled product potential information for one sample lodgepole pine stand. A comprehensive version including tabular results for nine representative small-stem lodgepole pine stands and a general purpose computer routine will be published by the Intermountain Research Station as a General Technical Report.

We defined four major objectives that needed to be met to provide maximum flexibility in a product prediction process for small lodgepole pine:

1. Develop a method for estimating gross product potential for a stand from a stand table. This method requires only the availability of a stand table for the timber being examined, and uses average total tree height in each diameter class.
2. Develop a method for estimating gross product potential for a stand from individual tree data, where detailed cruise plot records are available describing individual sample trees.
3. Develop a method for reducing gross product potential to net potential, for stands that have individual tree defect data available.
4. Apply gross and net product prediction methods based on individual tree records (items 2 and 3) to nine selected sample stands representing a broad range of tree size and stand density. Describe these stands sufficiently to allow direct comparison with stands of interest to managers.

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The study approach defined by these objectives was purposely chosen to accommodate a wide range of stand information availability. Information available to the manager may vary from detailed individual tree cruise data to aggregate stand table information, or perhaps only a general knowledge of the character of the stand. Objectives 1, 2, and 3 are directed toward providing methods that can effectively use individual tree or stand table information, while objective 4 is concerned with providing actual product information for sample stands that may then be compared to stands of interest.

PREDICTION SYSTEM DEVELOPMENT

Prediction system development made use of stand and tree data accumulated from 19 sample lodgepole pine stands geographically dispersed from the Wasatch-Cache National Forest (Utah-Wyoming) to the Lewis and Clark National Forest (north-central Montana). All stands were essentially pure lodgepole pine, ranging in stand density from 1 to 7 thousand green stems per acre, and in diameter from 7 inches d.b.h. down. They are broadly representative of the extensive overstocked, small-stem lodgepole pine stands occupying several million acres in the inland West.

The Stem Profile Table

The number and kind of roundwood products that can be obtained from a tree are determined by the profile of the stem--butt diameter, rate of taper and upper stem diameters, and length to some minimum useable diameter. As a basis for

Table 1--Stem profile table for lodgepole pine, indicating length to specified top diameters, by total height and diameter at breast height (d.b.h.) classes

Total height	Top diameter[1]	Diameter at breast height (inches) 3	4	5	6	7
Feet	Inches	Feet				
25	3	4	10			
	2	15	18			
30	4		4	10		
	3	4	13	18		
	2	19	22	24		
35	5			4	11	
	4		4	13	20	
	3	4	17	22	27	
	2	23	26	28	31	
40	5			4	14	22
	4		4	16	23	29
	3	4	21	26	30	35
	2	27	30	33	35	38
45	5			4	16	25
	4		4	19	26	32
	3	4	25	29	34	39
	2	31	34	37	39	42
50	5			4	19	27
	4		4	24	29	36
	3	4	28	33	38	42
	2	36	38	41	43	46
55	5			4	21	30
	4		4	26	32	39
	3		32	37	41	46
	2		42	45	48	50
60	5					32
	4					42
	3					50
	2					54

[1]Regression equations used (for top diameters less than d.b.h.):

Top diam.	Predicted length	R^2	se
2	-13.685 + 2.64(d.b.h.) + 0.826(hgt)	0.92	2.35
3	-27.687 + 4.698(d.b.h.) + 0.744(hgt)	.87	3.14
4	-40.979 + 6.51(d.b.h.) + 0.619(hgt)	.85	3.31
5	-56.613 + 8.233(d.b.h.) + 0.522(hgt)	.71	3.86

assessing product potential, we first developed a table of stem profiles that represented the range of tree diameter and height classes encountered on study sites.

An initial question to be resolved was whether tree d.b.h. and total height alone were capable of adequately explaining variation in "merchantable" stem length to various top diameters. We analyzed tree dimension data from the Montana and Utah/Wyoming sites separately, using stepwise regression methods to examine a number of independent variables, including tree d.b.h., total height, stand density, age, and site index. The analyses indicated that d.b.h. and total height were the only variables needed to predict stem length to specified top diameters. Density, age, and site effects are adequately reflected in the diameter-height relationship, and do not have to be accounted for separately. Any one stem d.b.h./height class can therefore be represented by a single stem profile, regardless of stand location or characteristics. Data from the Montana and Utah/Wyoming sites, totaling 341 destructively sampled trees, were consequently pooled to develop regressions predicting stem length to specified top diameters, for lodgepole pine trees from 3 to 7 inches d.b.h.

The next step was validation. A second sample of 103 trees was selected from seven of the study stands to cover the range of each d.b.h. class of interest. For example, in the 3-inch class one tree was chosen in each stand with d.b.h. between 2.6 and 2.8 inches, one with d.b.h. between 2.9 and 3.2, and one with d.b.h. between 3.3 and 3.5. The selected sample trees were felled and diameters were recorded at various heights up the stem. Comparisons of measured profiles for these sample trees with predicted profiles from the original stem length regression equations showed a high correlation.

The final step was to combine the original sample (341 trees) with the validation sample (103 trees) and recalculate stem length regression equations. Table 1 shows the resulting predicted stem length to specified top diameters for various d.b.h. and total height combinations. The regressions and tabled values are based on the total sample of 444 felled and measured trees from all 19 sample stands. The stem profiles described by the regressions and table should be representative of all lodgepole pine trees in the diameter and height classes shown.

Product Specifications and Values

Our intent was to develop a procedure that would predict product potential in terms of some common small-diameter products currently utilized by operators in the northern and central Rocky Mountain area. The product specification search revealed a large number of roundwood products with length and diameter requirements varying among manufacturers--and virtually no industry standardization. For example, one post and pole yard makes 37 different post products in addition to a variety of pole and sawed products.

A few products, however, are relatively standardized and represent the range of products and values the average operator might recover. Table 2 lists seven such products with lengths, minimum and maximum small-end diameters, and values per piece as well as per cubic foot. Values are an amalgamation of prices paid for raw material delivered to manufacturing points early in 1984.

Alternative Product Mixes

Using the stem profile table and the seven specified roundwood products, we developed a system to generate a matrix of all possible gross product alternatives for a tree of specified d.b.h. and height. This may be the average tree in a d.b.h./height class if a stand table is being used as input data, or the d.b.h. and height class of individual sample trees if individual tree records are used. Based on observations of the physical characteristics of small-stem lodgepole pine, certain standard operating rules were established. These constraints included taking 1 foot off the butt end of the tree to avoid butt swell, requiring that props and panel poles come only from the 3- and 4-inch d.b.h. classes (avoiding limby tops), and searching for barn poles only in the 7-inch d.b.h. class. We further specified a minimum "merchantable" top

Table 2--Product specifications and values for selected roundwood products commonly recovered from lodgepole pine

Product	Length	Small-end diameter Min.	Small-end diameter Max.	1984 value[1] Piece	1984 value[1] Ft^3
	Feet	Inches		Dollars	
Post	7	4	7	0.52	0.54
Rail	13	3	5	.65	.49
Rail	17	3	5	1.24	.67
Rail	21	3	5	1.45	.59
Prop	10	2.25	4	.50	.83
Panel pole	17	2	2.5	.50	.86
Barn pole	17	6	7	2.38	.62

[1]Prices paid for raw material f.o.b. manufacturing points.

diameter, above which products would not be recovered, for each d.b.h. class:

D.b.h. class	Minimum top diameter
3 and 4	2 inches
5 and 6	3 inches
7	4 inches

Table 3 gives alternative product mixes, residual stem volumes, and tree values for a range of total height classes within the 4-inch d.b.h. class. Residual volume is the unutilized cubic foot volume to the defined minimum top diameter. Similar tables were developed for the 3-, 5-, 6-, and 7-inch d.b.h. classes.

The matrix of alternatives for a particular diameter/height class can be used to pick the product combination that will maximize value. Or, an alternative with desired products can be selected. In the applications shown here, the alternative to maximize value has been used.

Approach to Defect

The estimation of gross product potential ignores the possible presence of defect in trees. If limiting or inadmissible defects are present in the stem or stand, actual product recovery will obviously be reduced. As part of this study, we examined alternatives for using individual tree defect data to adjust gross to net product potential.

Based on experience with local operators and a survey of manufacturing operations, we defined seven types of defect that influence product recovery. These were crook, fork, fire scar, catface, knot-cluster, mistletoe or canker swell, and sweep. We also developed criteria to assess the effects of defect occurrence on product potential.

Defect analysis was made using individual tree data collected from 1,817 sample trees on nine of the study sites. Table 4 gives a summary of the

Table 3--Alternative product mixes and values for the 4-inch d.b.h. class of lodgepole pine

Hgt.	Alt.	7-ft post	13-ft rail	17-ft rail	21-ft rail	10-ft prop	Panel pole	Residual volume	Value
								Ft^3	Dollars
25	1	0	0	0	0	1	0	0.23	0.50
30	1	0	0	0	0	1	0	.42	.50
	2	0	0	0	0	0	1	.32	.50
35	1	0	1	0	0	0	0	.46	.65
	2	0	0	0	0	2	0	.14	1.00
	3	0	0	0	0	0	1	.62	.50
40	1	0	1	0	0	1	0	.18	1.15
	2	0	0	1	0	0	0	.46	1.24
	3	0	0	0	0	2	0	.32	1.00
	4	0	0	0	0	1	1	.05	1.00
45	1	0	0	0	1	0	0	.45	1.45
	2	0	0	0	0	3	0	.08	1.50
	3	0	1	0	0	0	1	.08	1.15
	4	0	1	0	0	1	0	.36	1.15
	5	0	0	1	0	1	0	.18	1.74
	6	0	0	0	0	1	1	.49	1.00
50	1	0	0	0	0	3	0	.22	1.50
	2	0	0	0	0	2	1	.00	1.50
	3	0	0	1	0	0	1	.08	1.74
	4	0	1	0	0	0	1	.57	1.15
	5	0	2	0	0	0	0	.40	1.30
	6	0	0	0	1	1	0	.18	1.95
	7	0	0	1	0	1	0	.35	1.74
	8	0	1	0	0	2	0	.11	1.65
55	1	0	0	0	0	3	0	.40	1.50
	2	0	0	0	0	2	1	.11	1.50
	3	0	0	0	1	0	1	.08	1.95
	4	0	0	1	0	0	1	.58	1.74
	5	0	1	0	0	1	1	.02	1.65
	6	0	2	0	0	1	0	.14	1.80
	7	0	1	1	0	0	0	.40	1.89
	8	0	1	0	0	2	0	.26	1.65
	9	0	0	0	1	1	0	.35	1.95
	10	0	0	1	0	2	0	.11	2.24

Table 4--Summary of defect occurrence for the Corduroy Creek East sample stand

D.b.h. class	Number of defects			Locatable[1] defects by quarter[2]				Sweep
	0	1	2+	1	2	3	4	
Inches	Percent of stems							
3	18	27	55	76	36	22	31	0
4	24	27	49	57	19	27	38	0
5	32	42	26	58	26	10	16	0
6	14	57	29	50	57	7	21	0
7	100	0	0	0	0	0	0	0

[1]Locatable defects recorded included crook, fork, fire scar, catface, knot-cluster, and swell.

[2]Quarter segments are defined as quarters of merchantable stem length (1 = 0 - 25 percent).

defect occurrence found in one of the nine sample stands. The percentage of stems with 0, 1, or 2+ defects is shown by d.b.h. class. Also, the percentage of stems with defects located within each quarter of the merchantable stem length is reported by d.b.h. class. The exact location of each defect in the stem was recorded, as well as the length of stem affected by the defect. These defective lengths were then deducted from the stem and the remaining stem was searched for products.

Adjustment of potential product recovery to account for defect requires either individual tree defect information, as was collected for these nine stands, or a "defect factor" based on general experience. To adjust both the product mix recoverable and the value requires individual tree data. A "defect factor" can be applied only as an adjustment to total recovery and value.

APPLICATIONS OF THE METHOD

Managers have three alternatives for predicting product potential, depending upon the stand information available. Individual sample tree cruise data allow direct estimation of gross product potential, tree by tree, as well as reduction to net potential if tree defect information also exists. If information is limited to an aggregate stand table, gross product potential can be estimated using it alone. And if neither sample tree cruise data nor stand table data exist, a manager can simply use the gross and net product potential information developed for a sample stand that most nearly matches the stand of interest.

Gross Product Potential From a Stand Table

To estimate the gross product potential from a stand table, a measure of the average total height of trees in each d.b.h. class is needed. This allows the appropriate alternative product combination to be chosen for each diameter class. The number of products in chosen alternatives are then multiplied by stems per acre to give predicted gross products per acre. Table 5 is a stand table for one of the sample stands. For this stand table, the product combinations that maximize value are shown in table 6.

Table 5--Stand table for the Corduroy Creek East sample stand[1]

D.b.h. class	Average height	Stems/ acre	Volume/ acre
Inches	Feet	Number	Ft^3
3	40.1	750	810
4	46.1	617	1,339
5	50.7	317	1,160
6	54.5	233	1,300
7	57.7	33	262

[1]Based on inventory of all stems of 3-inch d.b.h. and larger on six 1/100-acre plots.

Gross and Net Product Potential From Individual Tree Data

Individual tree cruise data that include defect information provide the most reliable basis for product prediction. To demonstrate the use of individual tree data, we chose nine of the sample stands that represented a spectrum of typical stand conditions in small-stem lodgepole pine. Six to nine 1/100-acre plots were established in control units for each of these stands. Defect was identified and measured in all trees with at least a 3-inch d.b.h. Individual tree data were used to estimate gross and net product potential. The matrix of alternatives was used to obtain gross product potential with the assumption that each sample tree was free of defect. The information used was d.b.h. and total height. For the net product potential, trees were searched for products after all defective portions were eliminated.

Table 6--Gross product estimates per acre for the Corduroy Creek East sample unit, using the stand table as a basis for prediction

D.b.h. class	Products[1] 1	2	3	4	5	6	7	Residual volume	Value
Inches	Number							Ft^3	Dollars
3						750		172.50	375.00
4			617		617			111.06	1,073.58
5	634		317					15.85	722.76
6	699		233					25.63	652.40
7	33		33				33	0	136.62
Total									2,960.36

[1]Products: 1 = 7-ft post; 2 = 13-ft rail; 3 = 17-ft rail; 4 = 21-ft rail; 5 = 10-ft prop; 6 = 17-ft panel pole; 7 = 17-ft barn pole

Table 7--Gross and net product estimates per acre for the Corduroy Creek East sample unit, using individual tree records as a basis for prediction

D.b.h. class	Products[1] 1	2	3	4	5	6	7	Residual volume	Value
Inches	Number							Ft^3	Dollars
3 Gross					217	567		75.33	391.67
Net					167	250		292.50	208.67
4 Gross			433	83	467	33		162.50	908.17
Net		50	200		467	67		394.67	547.50
5 Gross	617		200	117				15.83	737.83
Net	467	17	217	66				177.00	618.74
6 Gross	650		200	33				25.67	634.33
Net	550	17	150	50				219.17	555.96
7 Gross	67		17				33	0	134.67
Net	67		17				33	0	134.67
Total Gross									2,806.67
Net									2,065.54
Reduction in total value due to defect									26.4 percent

[1]Products: 1 = 7-ft post; 2 = 13-ft rail; 3 = 17-ft rail; 4 = 21-ft rail; 5 = 10-ft prop; 6 = 17-ft panel pole; 7 = 17-ft barn pole

Table 7 shows the gross and net product estimates from individual tree records for one of the nine sample stands. This table also gives the unutilized volume to the minimum top diameter, the value for each d.b.h. class, and total stand value. The reduction in predicted total stand value due to defect was 26 percent. Product mixes changed in a few cases, and net residual (unused) volume is greater than gross residual volume. As expected, net value is less than gross value except in the 7-inch d.b.h. class, which had no defect. Figure 1 illustrates the gross and net values and shows that the greatest reductions due to defect were in the 3- and 4-inch d.b.h. classes.

Product Potential by Comparing Stands

The nine stands for which gross and net product potential have been calculated, based on individual tree data, represent a wide range of

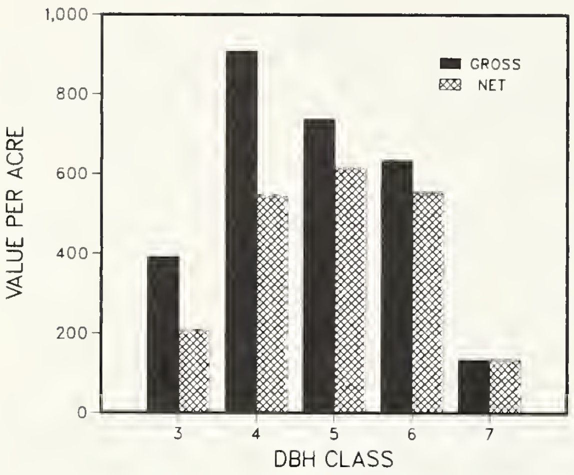

Figure 1--Comparison of gross and net values for the Corduroy Creek East sample unit.

stand conditions. In the absence of specific stand table or cruise data, or as a matter of expediency, a manager can simply use product information for one of these stands that most nearly matches a stand of interest. Important stand comparison criteria are size class distribution of stems, stand density, and defect occurrence. If a stand is similar in these respects to one of the nine stands analyzed, the product potential should also be similar.

Managers may also have stand information--a stand table, for example--that allows estimation of gross product potential, but no information describing defect in the stand. Comparison with one of the nine sample stands provides a way of choosing a "defect factor" or value reduction factor that can be used to adjust gross product potential.

ADDITIONAL INFORMATION

A major output of our study is a complete set of tables of alternative gross product mixes, such as table 3 illustrates, derived from the stem profiles for the defined group of products. The tables, covering lodgepole pine trees of various total heights in the 3- to 7-inch d.b.h. classes, will be contained in an Intermountain Research Station General Technical Report now being prepared. The report will include a general computer routine to generate similar tables for other user-specified products.

Also included in the report will be gross and net product potential information for the nine stands selected for complete analysis. Basic stand table and defect information for each stand will provide a way to compare other stands to these.

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AN ECONOMIC ANALYSIS OF PRODUCTION AND MARKETS: THE POST AND POLE SECTOR IN MONTANA

David H. Jackson and Kathleen O. Jackson

ABSTRACT: The post and pole sector of the wood products industry is a principal purchaser of small-diameter lodgepole pine material. A study was conducted to develop a better understanding of production processes, marketing, and distribution channels, and raw material demand and acquisition characterizing post and pole firms in Montana. This report is a brief summary of the full study report, which will be published separately.

INTRODUCTION

Small-diameter lodgepole pine timber historically has been a favored raw material in the post and pole sector of the wood products industry. Current interest in improving the management (and therefore, utilization) of extensive areas of small-diameter lodgepole pine has focused attention on such markets. Although considerable time and effort have been spent studying the lumber, plywood, and pulp and paper industries, much less is known about the post and pole business. Aside from a basic census of Montana's wood manufacturers, very little is known about post and pole production as a separate sector.

THE STUDY

The purpose of this study was to improve the descriptive and analytic level of information about Montana's post and pole industry. Specific objectives included characterizing the nature of the firms; describing products and product values; describing markets and distribution channels; identifying sources of raw material; and evaluating raw material demand and supply characteristics. Data were collected by interview with post and pole firms. The survey included 24 known producers in 1985, of which 88 percent provided the requested information.

Summary of a paper presented at Workshop on Management of Small-Stem Stands of Lodgepole Pine, Fairmont Hot Springs, MT, June 30-July 2, 1986. The full report by the authors is on file at the Forestry Sciences Laboratory, Intermountain Research Station, Missoula, MT. This brief summary was abstracted from the full report by Robert E. Benson, Research Forester, Intermountain Research Station.

David H. Jackson is Professor and Kathleen O. Jackson is Faculty Affiliate, University of Montana, Missoula, MT.

STUDY RESULTS SUMMARIZED

Results of the study include information portraying firms in the industry; characteristics of production, marketing, and distribution; and an evaluation of factors influencing raw material pricing. Raw material demand and price elasticity of demand are also examined, with implications for increased utilization.

Nature of Firms--Firms range from part-time, one-employee operations to plants with more than 20 annual employees. The average firm has the equivalent of seven year-long employees, counting full- and part-time employees. Payrolls average about $90,000 per year, ranging from about $6,000 to $500,000. About half the firms have capital (replacement) values of less than $10,000, and about half more than this amount.

Products--Firms in Montana marketed about 3 million cubic feet of products in 1985, with posts accounting for 56 percent. Poles and rails were the other major products. Based on product output, the industry in Montana is somewhat concentrated, with the four largest firms accounting for two-thirds of the output.

Markets and Distribution--About 43 percent of the products were shipped within Montana in 1985; 20 percent were shipped to California/Nevada, 13 percent to Colorado/Wyoming, and 13 percent to Nebraska/Dakotas. About 44 percent went to wholesalers, 21 percent to retailers, and 35 percent directly to end users. Agribusiness and its economic health is considered the most important market factor influencing producers' market potential. Highway and public works projects are also important contributors to market volume.

Freight rates and plant locations, both related to shipping costs, were also important factors. Larger firms marketed more outside the State than did smaller firms, and also used wholesalers more.

Raw Materials--Sources of raw materials for Montana plants were:

Source	Percent
National Forests	35.4
Private forest land	31.2
State forests	4.1
Other	29.3
Total	100.0

The most frequently cited problem in obtaining raw material was difficulty in finding woodcutters. Constraints on availability of timber and "red tape" in purchasing were also considered important factors adversely influencing acquisition.

Prices and Value Added--Products and purchaser's specifications for raw materials vary widely. To develop a basis for analyzing prices, three price equations were developed for short (5 ft to 10 ft), midlength (10 ft to 18 ft) and long (18 ft to 30+ ft) raw material. Similar equations were developed for products (posts, rails, poles) using additional processing variables such as peeling, treating, and pointing. From these equations, raw material price and product values can be calculated and used to estimate value added. For example, for a 6.5-ft post, 4-inch top, treated, the predicted values are:

Item	Value
Product selling price	\$1.80
Material purchase price	.47
Value added	\$1.33

The equations can be used to develop values on either a per-piece or per-cubic-foot basis.

Demand and Supply Schedules--In addition to the profile of the industry, the study developed estimates of the demand schedule for raw material and the supply schedule for products. Two approaches were used. A conventional production-function approach based on observed relationships between amounts of capital, labor, and raw materials indicated that no scale economies exist over the range of industry capacity observed. Marginal costs of labor and capital are constant, and therefore, the derived demand function is perfectly elastic. In such a situation, quantities of raw material demanded and products produced are infinitely sensitive to price (but in practice, are purchased or sold at only one price--the prevailing market price).

An alternative "willingness to pay" approach was also used. Producers were asked what would happen if raw material prices or product prices were to change. Based on the responses, the price elasticity of demand for raw materials was estimated to be -1.52; that is, raising the costs of raw material by 1 percent would decrease the amount of raw material demand by 1.52 percent. Regarding product output, it was estimated that the price elasticity of supply of post and pole products offered is +1.97; that is, a 1 percent increase in product prices would increase the amount offered by producers by 1.97 percent.

The results indicate rather strongly that demand for raw material and products are price-elastic. Price changes would result in more than proportional changes in quantities of raw material purchased and products produced.

CONCLUSIONS

Five general conclusions were drawn regarding the Montana post and pole industry:

1. The industry is limited by markets, not by raw material supply or other production factors.

2. The economic health of agribusiness is the most important factor affecting market size.

3. National Forests are an important, but not dominant, supplier of raw material to the industry.

4. Demand for raw material is price-elastic; for a given percent increase in material costs, the amount demanded by post and pole producers will decrease by a greater percentage.

5. Supply of finished products is also price-elastic; for a given percent increase in product prices, producers would increase the amount offered by a greater percentage.

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A SITE-SPECIFIC ASSESSMENT OF POTENTIAL WOOD RESIDUE USES IN NORTHWESTERN MONTANA

Charles E. Keegan III

ABSTRACT: An estimated 100,000 to 150,000 dry tons of mill residue suitable for fuel should be available annually to a new user in northwestern Montana. Whole-tree recovery systems can provide the lowest cost forest residue for use as fuel. Small timber would also be available as residue from timber stand improvement projects. Uses of wood as a substitute for coal, or to generate electricity, generally could not support recovery of small timber. Wood as a substitute for fuel oil and natural gas could in some cases support the cost of harvesting small timber.

INTRODUCTION

In this paper I will discuss results of a site-specific assessment of wood residue utilization opportunities in northwestern Montana--specifically the area surrounding Libby, MT. The project was a cooperative research effort between the Bureau of Business and Economic Research at the University of Montana and the Intermountain Research Station of the Forest Service, U.S. Department of Agriculture. Ron Barger of the Forestry Sciences Laboratory in Missoula was the major Forest Service participant. The results will be reported in detail in "Utilizing Wood Residue for Energy in Northwestern Montana: An Assessment of Feasibility" (Keegan and others), a General Technical Report currently in preparation at the Intermountain Research Station.

Here I will:

1. Briefly describe the project and some of the project's results focusing on what components of wood residue offer the best opportunity to supply additional increments of wood fiber for utilization.

2. Examine what various users, especially energy users, might be able to pay for wood fiber.

3. Relate this to estimated costs of harvesting and delivering small timber.

Paper presented at Workshop on Management of Small-Stem Stands of Lodgepole Pine, Fairmont Hot Springs, MT, June 30-July 2, 1986.

Charles E. Keegan III is Associate Director of the Bureau of Business and Economic Research at the University of Montana, Missoula, MT 59812.

The project had two major goals: (1) development of methodology that would be applicable throughout the Intermountain and Pacific Northwest regions in other site-specific assessments, and (2) an actual assessment of feasibility of increased wood residue utilization in the northwestern Montana area with an emphasis on the use of residue for energy.

The project resulted in five major types of information:

1. The methodology.

2. A wood residue supply schedule, which indicates estimated volumes of particular components of the wood residue resource available for different cost levels.

3. An assessment of regional demand for low-value wood fiber based primarily on current and planned capacity for reconstituted product uses and industrial fuel use. We also examined what users might be able to pay in competition with each other.

4. A financial analysis of various wood-fired facilities to generate electricity and analyses of the use of wood as a substitute for natural gas, fuel oil, and coal.

5. An identification and evaluation of additional constraints and benefits to increased wood residue utilization.

COMPONENTS OF THE RESIDUE RESOURCE

We fit wood fiber residue first into two major categories: mill residue and forest residue. Mill residue is generated in the manufacture of lumber, plywood, and other primary wood products. In the Inland Northwest, residue from lumber and plywood plants accounts for virtually all of this type of residue, and this is where the analysis was concentrated.

The second major category--forest residue--we defined broadly as any unutilized or underutilized component of the available timber resource.

MILL RESIDUE AVAILABILITY

In years of average or higher lumber and plywood production our projections indicate a surplus of mill residue suitable for fuel. It should be

mostly bark and sawdust. Although this surplus is a large problem for individual mills and represents a serious disposal problem, it is small relative to the total supply of mill residue and small relative to current demand. Total supply also varies directly as lumber production varies. Therefore, the surplus could disappear in the short term with a recession in the lumber industry or in the long term due to changes in total sawmill capacity or demand.

Currently, I believe users in northwestern Montana or northern Idaho could secure through long-term contracts 150,000 dry tons annually (12 million ft^3) at a delivered cost of $10 to $30 per dry ton. This would be about 120,000 cunits (a cunit is 100 ft^3 of solid wood) at an estimated cost of $12.50 to $37.50 per cunit. Again, this material would be mostly in the form of bark and sawdust. Lesser amounts would be available in other parts of the State.

FOREST RESIDUE AVAILABILITY

Forest residue includes a wide array of material. We dealt with it in the following categories:

1. Logging residue--unutilized material that would be available in conjunction with sawtimber harvest operations.

2. Timber stand improvement residue--residue from thinning and stand conversion operations. Thinning residue is material cut and generally left at the operation site. Stand conversion residue is cut to convert stagnant, improperly stocked stands to younger, properly stocked stands.

3. Untreated slash from previous logging operations.

4. A catch-all category--all other material not included in other categories and not part of sawtimber or sawtimber growing stock. Generally this is material at sites not scheduled for harvest or other treatments.

We were fortunate to undertake our project at the same time that the Pacific Northwest Research Station of the Forest Service was cooperating with the Intermountain Research Station on an inventory of recently logged-over lands in Montana. The results indicated that although relatively large volumes of wood fiber are currently left at logging sites, virtually all of it is in pieces too small to consider recovering in its present state. What is commonly thought of as logging slash, large dead and cull green logs, does not exist in large quantities in Montana.

What then is available? Our conclusion was that the best opportunity to utilize forest residue for fuel would be to recover through whole-tree logging systems the tops and limbs of sawtimber trees or pulpwood trees being harvested to recover products from the bole. Theoretically, this is low-cost wood fiber, although this has not been verified through field trials in Montana. Our estimates of cost were $20 to $50 per ovendry ton or $25 to $65 per cunit.

The only other component we felt would offer opportunities to a large-volume user would be small timber available in timber stand improvement projects. This--especially small-diameter lodgepole pine--of course, is also material suitable for some specific roundwood product uses. Costs of recovering this material vary tremendously. However, by choosing the most favorable harvest opportunities in 4- to 8-inch-diameter timber, our estimates indicate a user could recover moderate volumes for $30 to $50 per ovendry ton or an estimated $40 to $65 per cunit.

SMALL TIMBER FOR ENERGY AND PRODUCT USES

Small timber has different values for various uses and this value relates to the recovery cost of the timber. I will use the term "value use range" to mean an estimate of what plants or facilities of various types might pay for delivered wood and still operate profitably.

Figure 1 depicts the value use range of timber delivered for various uses. Value use is depicted by the solid bars across the face of the graph. The uses are identified in groups comprised of energy uses, reconstituted products, and solid products. The energy uses include wood used to generate electricity and as a replacement fuel for coal, natural gas, and fuel oil. The reconstituted products uses are particleboard, fiberboard, waferboard, and pulp and paper manufacturing. The solid products are posts and rails, studs, and houselogs.

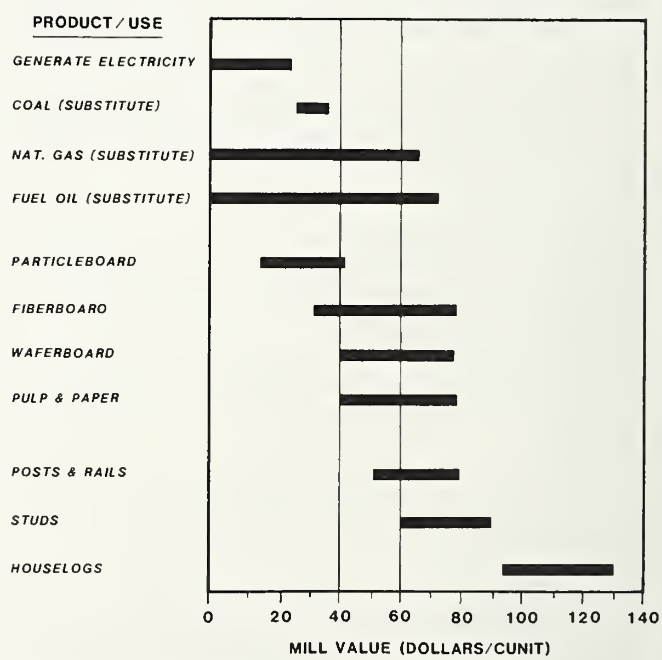

Figure 1--Estimated value use of wood fiber for energy and selected products in the Inland Empire Region (1984 dollars). Bureau of Business and Economic Research, University of Montana, Missoula, MT.

The two vertical lines represent what I have called a realistic, but somewhat optimistic, estimate of the cost to harvest and deliver small timber in relatively large quantities--in excess of 1 million ft^3 per year delivered to a single facility through recovery of thinning and other timber stand improvement residue. The estimates are $40 to $60 per cunit or $30 to $45 per oven-dry ton.

As figure 1 indicates, energy uses generally rank below product uses. Generating electricity was identified as a very low value use for wood. I think there is virtually no opportunity for a private sector investor using conventional sources of capital to harvest timber--small or large--and generate electricity profitably in Montana.

There also appears to be little, if any, opportunity to substitute wood for coal. Little coal is used in the timber-producing regions of the State, and proposed wood-fired projects have not developed partly because of the low cost of coal in other areas. The use of wood as a substitute for natural gas and fuel oil had the highest potential for energy use. At prices of $65 and $70 per cunit, small timber could certainly be harvested. The opportunities to utilize small timber as a substitute fuel may not look as good as the $65 or $70 per cunit maximum value indicated, however. First, note the large size of the ranges 0 to $70 and 0 to $65. This is because of large variability in capital costs of the systems and capacity utilization of heating systems. Primarily because of this variability, use of wood as a substitute for natural gas or fuel oil must be evaluated on a case-by-case basis.

Two additional factors also impact the use of wood in place of these fuels. Currently, natural gas and fuel oil prices are lower than those used in our analysis, and substantial increases are not projected for the near term. In addition, a new rate structure allows power companies in Montana to offer low natural gas rates to users with opportunities to switch to other fuels.

OUTLOOK FOR USING SMALL TIMBER FOR ENERGY

I would expect no large-scale use of small-diameter timber for energy in the next 5 years. Generating electricity, which could be a very high volume user of wood fiber, would require much higher electrical rates than are currently in effect before small timber could be used. Further new power would be based first on sources such as coal, hydro, and cogeneration using mill residue (and perhaps logging residue in the form of tops and limbs of sawtimber trees). These would all be cheaper than power based on harvesting small timber.

Some nearer term opportunities may exist for industrial and institutional users to shift from fuel oil and natural gas to wood. The lower cost of fuel oil and natural gas and a new rate structure do not make the use of harvested timber impossible, but certainly less attractive than a year ago. The key will be what happens to oil and natural gas prices. I believe in the long term, the role of wood for energy in Montana--which is already important--will expand. But looking at small-diameter timber and lodgepole pine in particular, I do not foresee any developments on the immediate horizon that will support a level of utilization sufficient to solve some of the very large management problems that exist.

UTILIZATION OF LODGEPOLE PINE--
IDENTIFICATION OF THE PROBLEM AND A PROPOSED PARTIAL SOLUTION

Peter Koch

ABSTRACT: Lodgepole pine is dominant on about 13 million acres of commercial forest land in the United States; most of these acres are in the Rocky Mountains, and nearly half the volume in the Rockies is in Montana. Because of small diameters, most lodgepole pine offers little opportunity for profitable processing through conventional sawmills. The public land manager faces the problem of how to clearcut and regenerate large acreages of stagnated or otherwise unproductive stands of lodgepole pine without expending public funds to cover the direct costs, and to accomplish this stand replacement according to a management plan without jeopardizing the other values of the forest. Such stand replacement with vigorous new stands is done in contemplation of precommercial thinning to a prescribed stocking density when the new trees reach a height of about 15 to 20 feet. To partially solve the problem, an operation is proposed that would harvest (clearcut) 2,400 to 3,600 acres per year from stagnated lodgepole pine stands for delivery to a major center for segmenting whole trees into components to maximize tree value. Products would include conventional roundwood items (cabin logs, tree stakes, posts and poles), 2 by 4 studs, structural flakeboard, and fabricated joists employing flakeboard webs and minimally machined lodgepole pine stems as flanges.

INTRODUCTION

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is the fourth most extensive timber type west of the Mississippi River and is dominant on about 13 million acres of commercial forest land in the United States. Most of these acres are in the Rocky Mountains, and nearly half the volume in the Rockies is in Montana.

In an attempt to improve utilization of lodgepole pine, a several-stage research effort was initiated in 1983. In the first stage, now completed, the world literature on the species was accumulated, keyworded, and appropriate data were entered to permit ready computer retrieval. Almost all the publications deal with forestry aspects--regeneration, protection, and growth and yield--only a miniscule fraction of the literature is concerned with utilization of lodgepole pine.

Paper presented at Workshop on Management of Small-Stem Stands of Lodgepole Pine, Fairmont Hot Springs, MT, June 30-July 2, 1986.

Peter Koch is President of Wood Science Laboratory, Inc., Corvallis, MT 59828.

Next, the North American population of lodgepole pine (var. *latifolia*, and less intensively *murrayana*) was systematically sampled at 2.5° latitudinal intervals throughout the range of the species from 40 to 60° north latitude (fig. 1).

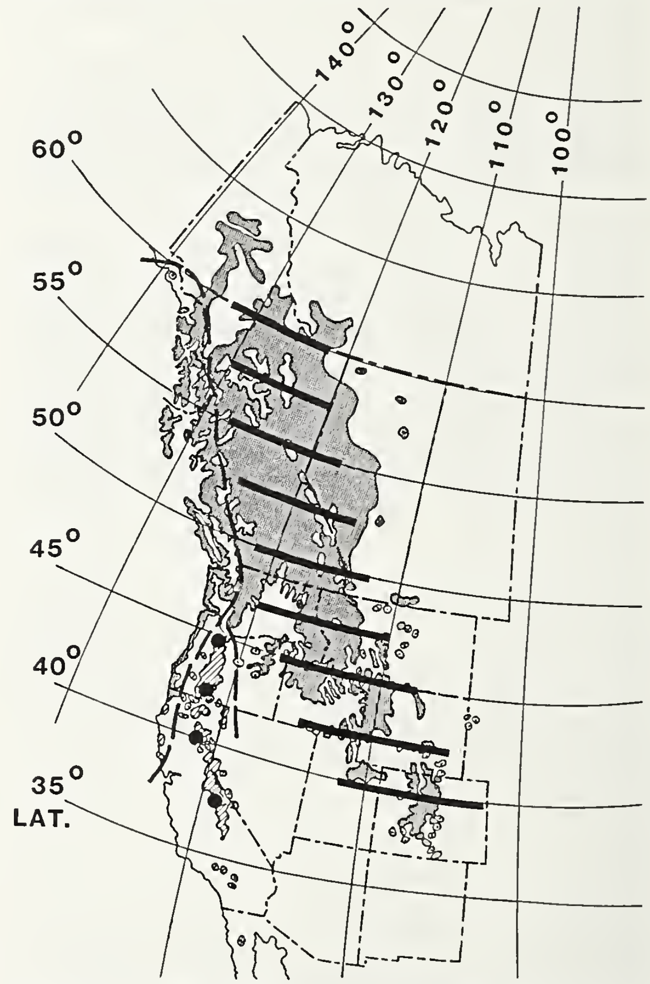

Figure 1--Sampling zones superimposed on Little's range map of lodgepole pine in North America. Variety *latifolia* is mapped to the right of the dashed lines, *murrayana* between them, and *contorta* to the left of them. Variety *contorta* was not studied because of its small potential for commercial use.

Results showed (Koch 1987) that properties of lodgepole pine vary significantly with latitude, elevation, and diameter class. For example, trees in Canadian latitudes have fewer open (nonserotinous) cones, higher specific gravity, more heartwood, less taper, and much lower moisture content than those in the United States.

Trees from higher elevations within a latitudinal zone have more within-crown taper and thinner sapwood than those from lower elevations within the zone. Tree diameter class has a strong inverse correlation with stemwood specific gravity. Entire stemwood of trees 3 inches in diameter at breast height (d.b.h.) had average specific gravity (based on ovendry weight and green volume) of 0.43, 6-inch trees averaged 0.42, and 9-inch trees averaged 0.41. At stump height, trees 3, 6, and 9 inches in d.b.h. averaged 71, 91, and 107 years old, respectively.

In the third step, 28 representative public land acreages in the United States were identified (fig. 2) for which the responsible land managers seek intensified utilization. They range in size from 2,000 to 75,000 acres. During the summer of 1986, I visited each of these acreages to study the problem and to accumulate data preparatory to publication of an atlas (Koch and Barger in preparation) describing the areas. This 1986 work was done under a contract with the University of Montana; major funding was provided by the Intermountain Research Station, Forest Service, U.S. Department of Agriculture.

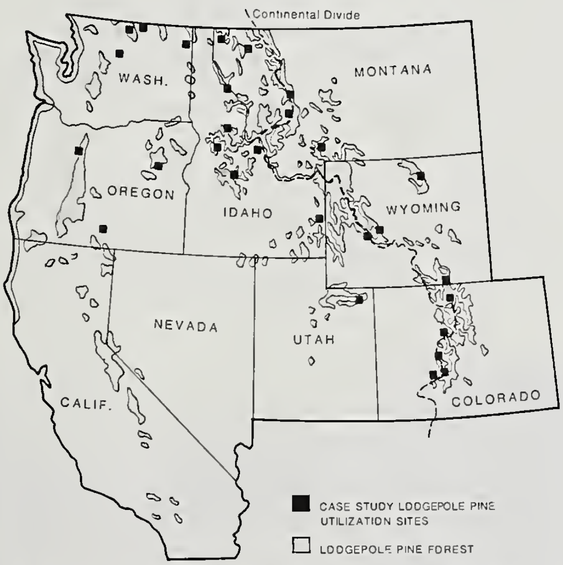

Figure 2--Locations (marked by black squares) of 28 representative acreages on public land in the United States for which the responsible land managers seek intensified utilization of lodgepole pine. The shaded area indicates extent of lodgepole pine forest type.

From these sequential operations, I have defined the problem as it appears to me, and arrived at a possible partial solution.

PROBLEM DEFINITION

The 28 acreages visited differ greatly. For example, although most are solidly forested in lodgepole pine, some contain significant amounts of larch, Douglas-fir, subalpine fir, spruce, or aspen. Meadows and grassy openings are common in the lodgepole pine acreages of Colorado, southern Idaho, and Wyoming. Growth potential varies from only slightly more than 20 cubic feet per acre per year to more than 100 cubic feet per acre per year. Annual precipitation varies from a low of slightly less than 20 inches to a maximum of near 40 inches. Terrain varies from nearly level to mostly steep; in aggregate, perhaps two-thirds of the lodgepole pine acreage delineated is on slopes of less than 45 percent. A few of the acreages are stony and strewn with boulders, but most are not excessively rocky.

Mortality--primarily from mountain pine beetle attacks--varies from most to virtually none of the stems. Defects in live trees that adversely affect utilization in solid wood products include porcupine scars (in some areas occurring on three-quarters of the stems and at several heights on each stem), stem crook, stem sweep, stem fork, cankers, fire scars, frost cracks, pith eccentricity, and excessive compression wood content, spiral grain, taper, and limbiness. Degree of defect varies greatly among and within acreages.

Accessibility of the acreages also varies significantly. Almost all have roads to their perimeters, and most have some interior roads; but a few can be reached only on foot. Most are within 50 miles of a railhead, but a few are more distant.

In virtually all of the acreages, stand type varies in a continuum. Classes of stands include "dog-hair" stands of trees less than 3 inches in d.b.h., pole stands with all trees live, pole stands with many dead trees, pole stands with dense understories of smaller trees, stands of sparsely stocked small sawtimber--usually over 200 years old, vigorous stands of large pole timber (6 or 7 inches in d.b.h.), stands of dead trees killed by bark beetles--many of suitable size for cabin logs--and stands of a variety of ages and generally low stocking containing relicts of past insect attacks as well as a range of smaller trees--usually suffering from mistletoe attack and cankers of various descriptions.

Most of the lodgepole cubic volume on the acreages visited is found in trees 3 to perhaps 6.5 inches in d.b.h.--trees too small to yield sawlogs. Trees are typically about 70 to 100 years old, with few stands less than 40 years old and some over 200 years old.

In the d.b.h. class from 3.5 to 4.0 inches, trees are generally about 35 feet tall, with few shorter than 22 feet and few taller than 55 feet; stemwood-average specific gravity of such trees ranges from 0.36 to 0.52, but is generally 0.40 to 0.44 (based on ovendry weight and green volume). For trees 3.5 to 4.0 inches in d.b.h., crown ratios are mostly in the range from 30 to 60 percent with the average slightly less than 50 percent. Below-crown stem taper (inside bark) is generally more than 0.4 and less than 0.8 inch per 100 inches, and averages about 0.6 inch.

Data from Montana lodgepole stands selected for 1985 thinning studies suggest that an average unthinned acre might contain 1,360 live stems 3 inches in d.b.h. and larger, totaling 3,400 cubic feet of stemwood, or about 43 tons of stemwood (ovendry basis). Considering all the 28 lodgepole pine stands I visited, however, it seems to me that a more conservative estimate for lodgepole in the Rocky Mountain area might be 1,000 live stems per acre measuring 3 inches in d.b.h. and larger, totaling 2,500 cubic feet of stemwood, or about 31 tons of stemwood, ovendry. When more accurate inventory data are available, even this lower estimate may prove too high.

On virtually all the acreages, post and pole operators nibble away at the pole stands, each cutting 1 to 3 acres annually near existing roads; such post and pole operations are sometimes used to achieve cosmetic thinning along these roads. These operators generally pay a stumpage fee of $5 to $7 per thousand lineal feet of product.

On Colorado and southern Wyoming acreages, some lodgepole pine Christmas trees are cut annually (stumpage fee of $3 to $5 per tree for personal use). Almost all acreages have a significant market for dead stems sold as firewood (usually $2.50 to $12.50 per cord stumpage fee). Firewood stumpage values frequently exceed sawlog stumpage values.

Occasionally, a sawlog sale of 15 to 500 acres is made, but virtually always at a stumpage cost less than that required to prepare the sale. Sawlog sales of more than 12,000 board feet per acre are unusual, and stumpage fees usually are in the $6 to $10 range with some sales made at $1 per thousand board feet (Scribner log scale), and a few as high as $25.

Costs of preparing and executing a small-acreage, low-volume sawlog sale, exclusive of road construction cost, vary greatly among administrative units and also depend on the characteristics of the sale area. Sale costs per thousand board feet of sawlogs are inversely related to sale acreage and to timber volume sold per acre. Sales in the areas studied usually encompass less than 40 acres, with lodgepole pine sawlog volume generally less than 8,000 board feet per acre.

The direct costs to Ranger Districts (or equivalent in State or Bureau of Land Management forests) were reported as low as $2 in one area, but more typically are $12 to $25 per thousand board feet, Scribner scale. When all appropriate direct and indirect costs within Ranger Districts, Supervisors' Offices, and Regional Headquarters are included; however, total sales costs per thousand board feet of lodgepole pine sold in small tracts appear to be in the range from $40 to $60, with one forest reporting total costs of $85. Such costs include not only those incurred by technicians, timber sales officers, and road planning engineers but also those incurred by specialists in silviculture, wildlife habitat, landscape esthetics, watershed quality, archeology, and law (together with all supporting staff in Supervisors' Offices and Regional Headquarters).

Volumes of forest residues resulting from sawlog sales in these problem lodgepole pine stands are generally great because most of the sawlog operators have no profitable outlet for subsawlog-size stems.

MANAGEMENT OBJECTIVES AND SILVICULTURAL CONSIDERATIONS

With virtually no exceptions, the land managers have concluded that thinning these more-or-less stagnated stands that are 70 to 100 years old is an uneconomic procedure; this is so because products recovered in such thinnings have low value, growth response is not outstanding, and thinning cost is great.

With almost no exceptions, the land managers are seeking some method to replace the stagnated and unmarketable stands of lodgepole pine with new vigorous stands of the same species--and they want to do this without expending public money. They visualize that this must be done by phased clearcutting and natural regeneration, but they have very few stumpage purchasers willing to build the necessary temporary roads, fell all diameter classes of all species, and leave the acreage with no more than 25 tons (ovendry) of slash per acre and with sufficient seed distributed on exposed mineral soil to ensure natural regeneration (fig. 3). When the managers contract such stand replacement operations, they incur costs of $200 to $700 per acre--costs that they find hard to justify economically. Most of the managers do not find it necessary to plant such clearcut areas if the seedbed is properly prepared, with mineral soil adequately exposed and viable seeds available from serotinous cones on the ground or from adjacent trees bearing open cones.

Figure 3--Lodgepole pine was harvested from this clearcut in south-central Colorado with a steep-slope feller-buncher. Very small stems were trampled. All slash was left on the ground unpiled and unburned. Regeneration will be natural. The access road is temporary.

Assuming that stand replacement can be accomplished with little or no expenditure of public

funds, most of the managers think that they can internally fund thinning of the regenerated stands when the trees are 15 to 20 feet tall (fig. 4); cost of such precommercial thinning is usually $60 to $85 per acre, but may be as high as $300 per acre if vegetation is dense.

Figure 4--Naturally regenerated lodgepole pine in southern Wyoming precommercially thinned at about 18 years to 350 to 400 stems per acre. In the proposed utilization problem solution slash would not be piled or burned, but would remain as shown to deteriorate slowly. Stadia rod in center foreground shows 1-foot intervals.

In virtually all cases, the managers must give great consideration to improvement of wildlife habitat, protection of stream quality, and protection of esthetic values--but these considerations are not generally seen as prohibiting planned stand replacement as long as clearcuts do not exceed 40 acres, are spaced to maintain elk or deer hiding cover, do not disturb streams, and are located and contoured to be visually acceptable. This generalization does not apply to two or three of the Wyoming-Colorado areas where recreational use is heavy and where hiding cover for elk is limited to a narrow forest of lodgepole pine bordered by sagebrush below the trees and exposed rock above.

Although controlled or wildfire might appear to offer a solution on some acreages, few managers are willing to embrace the idea of deliberately wasting the enormous tonnages of wood that would be consumed by such fires. And such fires would have limited usefulness in protecting stream quality, habitat, and esthetic quality of the forest.

SUMMARY OF THE PROBLEM

In brief, the land manager faces the problem of how to clearcut and regenerate large acreages of stagnated or otherwise unproductive stands of lodgepole pine without expenditure of public funds to cover the direct costs. Additionally, managers must accomplish this stand replacement according to a management plan without jeopardizing the other values of the forest--wildlife habitat, stream quality, and esthetic quality. Such stand replacement with vigorous new stands is done in contemplation of thinning to a prescribed stocking density when the new trees reach a height of about 15 to 20 feet. Additionally, biomass resulting from the clearcuts should yield a positive contribution to the economy--as contrasted to waste through destruction by fire, or by insects and disease.

At the same time, the industrial manager of the operation performing the clearcutting, site preparation, and utilization of the material removed faces the problem of making an appropriate profit on investment in harvesting, transport, and conversion facilities. This after-tax return should be at least 15 percent annually on the entire investment, assuming no borrowed funds.

PROPOSED SOLUTION

At the outset it should be understood that the contemplated operation in the forest is a stand replacement, not a timber sale. That is, the company planning to utilize the biomass will--in a no-cost exchange for most of the biomass on each acre--agree to:

- Build the necessary minimum-quality and temporary access roads to permit making the required clearcuts prescribed by the long-range management plan; at least in the initial decade of the plan, these clearcuts will be made on land having slopes less than 55 percent. It will be the responsibility of the land manager to construct the principal haul road serving the area.

- Shear (or saw-fell) and remove from the forest essentially all of the aboveground biomass of all trees of all species larger than 3 inches in d.b.h. (with the exception of sufficient cone-bearing branches to favor regeneration). If the stand lacks sufficient viable seed, the public land manager will be responsible to provide supplementary direct seeding at the appropriate time.

- Trample all stems 3 inches and less in d.b.h.; this should result in less than 25 tons (ovendry basis) of slash on the ground; this slash would be neither piled nor burned--simply compacted by trampling and subsequent snowfall.

- Equip feller-bunchers and skidders with treads designed to expose a maximum of mineral soil to favor natural regeneration. In areas with insufficient mineral soil exposed because they were logged in deep winter snow, or for other reasons, it will be the responsibility of the land manager to roller chop--or otherwise adequately prepare the seedbed--according to prescription.

- To avoid unnecessary drain on the forest nutrient pool, restrict pile and burn operations to landings only, where slash may accumulate.

Harvesting

Steep-slope feller-bunchers equipped with accumulators and shears (fig. 5) teamed with fast grapple skidders (fig. 6) or forwarders, capable of operating on slopes up to 55 percent, will comprise the primary harvesting equipment. In addition to felling, bunching, and forwarding (1,000 feet) about 1,400 trees per 8-hour day, these vehicles should be able to effectively trample most of the small trees during all seasons, and accomplish needed mineral soil exposure under all but deep-snow conditions.

Figure 5--Track-mounted steep-slope feller-buncher equipped with self-leveling platform carrying a boom-mounted tree shear that can accumulate sheared stems preparatory to depositing them in a bunch.

Figure 6--Track-mounted grapple skidder rapidly moving bunched trees down a steep slope.

Transport of Trees to Plant

Trees from most acreages will have small crowns and will be transported to the mill (fig. 7) with crowns attached. Stems from some stands will have such heavy crowns that they will have to be delimbed before transport.

Figure 7--Whole pines with small crowns loaded full-length on a truck for transport to mill.

Storage of Trees at the Mill

Trees will be off-loaded by crane at the mill, stored in high decks, and sprayed with water in summer when risk of fungal stain is high. Unresolved is the problem of winter retrieval from the high decks without major stem breakage under conditions when the stems freeze together into unmanageable blocks; some experienced mill managers believe that trees with crowns intact have less tendency to freeze together than limb-free stems.

Delimbing

Before passing to the debarker, all stems will be delimbed mechanically. After delimbing but before debarking, tree portions (from both live and dead trees) suitable for cabin logs will be removed by crosscut sawing and shunted into storage preparatory to hand debarking and further manufacture.

Debarking

With the exception of tree portions removed for cabin logs, all stems will then pass through mechanical ring debarkers, and the bark will be conveyed to a processing plant for conversion to soil-amendment products or to heat energy.

Stem Merchandising

From the debarkers, all stems will pass to a merchandising machine equipped with scanners and computer-controlled bucking saws designed to segment each stem into pieces of maximum value for later conversion into roundwood products such as tree props (a pointed dowel 2 to 2.25 inches in diameter and 6 to 12 feet long), post and rail products of various kinds, joist flanges (fig. 8), stud logs, and telephone or power poles.

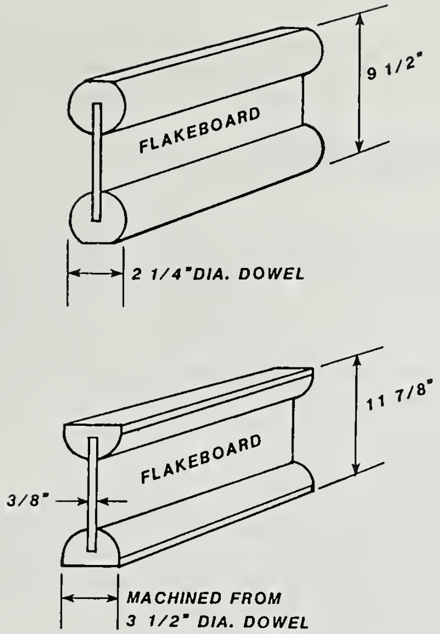

Figure 8--Joists fabricated with minimally machined lodgepole pine dowel flanges and 3/8-inch-thick flakeboard webs. By finger jointing flanges into long lengths, joists of any desired length can be fabricated. By varying dowel (or half-dowel) diameter and spacing, joists with desired stiffness and load-carrying capacity can be constructed.

Most of the output will be tree props and flanges for fabricated joists (Koch and Burke 1985) because these are high-value, high-volume products and because most of the stems will have diameters appropriate for these products. Because the market for fenceposts and rails is limited, only a small portion of total output will be converted into these products (some of which will be pressure impregnated with the preservative CCA, as required by the market).

Residues

Stembark (see Debarking, earlier) will be combined with organic wastes (perhaps sewage sludge) and processed into soil-amendment products with value sufficiently high to warrant shipment to distant markets. Alternatively, it can be burned for heat energy.

Branchwood and branchbark (most foliage will be lost during skidding and transport) will be used as fuel to warm the plant during winter, and to satisfy the heating requirements of kilns to dry joist flanges and lumber cut from the stud logs.

Most stemwood green residues will be converted to flakes 3 inches long, about 0.020 inch thick, and generally less than 1 inch wide. These stemwood residues will come from several sources:

- Thirty-two-inch-long stem sections cut from stems that have butts shattered by felling shears (32 inches, because this is a length appropriate for conversion by a disk flaker).
- Thirty-two-inch-long stem sections removed because they include short crooks.
- Eight-foot-long stem sections too defective or crooked for conversion to roundwood products (8 feet, because such bolts can be crosscut into three 32-inch lengths before flaking).
- That tapered portion (about 50 percent of each stick doweled) of stemwood removed during doweling operations; the problem of designing dowelers that will produce a residual flake having the qualities needed for flakeboard is unresolved.
- All stems of species other than lodgepole pine (for example, subalpine fir, aspen, spruce) will be crosscut first to 8-foot lengths and later to 32-inch lengths for flaking.

Unavoidably, some random-length stem sections shorter than 32 inches will result from cutting random-length stems into products that for the most part have specified lengths. These trim ends will be chipped for pulp; alternatively they can be added to the chipped branches to fuel the dry kilns and provide plant and process heat (including heat needed for the flakeboard hot press).

Also, stemwood tops with butt diameters less than 2.25 inches likely are too small for flaking and will have to be chipped for pulp or fuel. Such tops might each contain about 0.1 cubic foot of wood and have an ovendry weight of perhaps 2 pounds. This portion of harvested stemwood residue probably will total about 1 ton per acre (ovendry).

Additionally, green sawdust from the studmill and dry planer shavings from stud planing operations (as well as sawdust and shavings from manufacture of joist flanges) will help fuel the dry kilns and provide plant and process heat.

Flakeboard Manufacture

Flakes residual from manufacture of roundwood products will be dried and screened. About 80 percent of the dried flakes will be accepted for conversion into structural flakeboard (fig. 9). Fines comprising the remaining 20 percent will be routed through a suspension burner to provide heat for the flake dryer. Unresolved is the question of economic control of emissions from the suspension burner-dryer mechanism.

The manufacturing operations, and hence the scale of harvesting operations, will be sized to yield structural flakeboard production of about 100 million square feet annually, 3/8-inch basis. Such board might typically weigh about 40 pounds

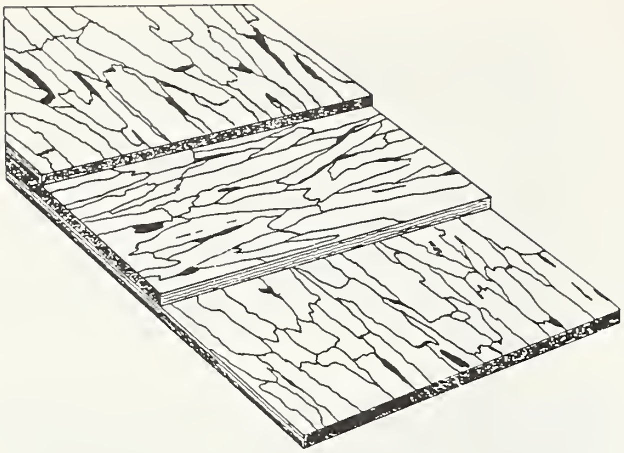

Figure 9--Structural flakeboard. Such board can have random orientation of flakes, or as shown here, be comprised of three layers each with strands oriented. In oriented-strand board, flakes in the two face layers are aligned with grain parallel to the 8-foot edges of 4- by 8-foot panels, and those in the core at right angles to this.

per cubic foot, ovendry basis. With resin and wax content subtracted, each cubic foot of board might contain 39 pounds of wood, ovendry basis.

If 75 percent of the stemwood harvested goes to the flakeboard plant, and four-fifths of this leaves the plant as salable board, then annual stemwood harvest can be estimated as 101,563 tons per year, ovendry.

If, as Montana data suggest, an average acre yields 43 tons (ovendry) of stemwood from trees larger than 3 inches d.b.h. (1,360 of such trees per acre), then the annual area to be clearcut will total about 2,362 acres.

If, however, an average acre in the Rocky Mountains yields only 31 tons (ovendry) of stemwood per acre in trees larger than 3 inches in d.b.h. (1,000 of such trees per acre), then the area to be clearcut annually will total about 3,276 acres.

Economic Feasibility

It remains to be seen whether the operation described is economically feasible. A study to make this determination is scheduled for 1987.

Comment on Scale of Operations

There are only a few locations where an operation of the scale described (2,300 to 3,300 acres to be clearcut annually) might be feasible. Needed in addition to the proposed large-scale operation, but not yet conceived, are economically viable stand replacement operations for much smaller acreages that would clearcut 250 to 500 acres per year over a plant life of 20 years.

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Biological Responses

Chaired by: Roger D. Hungerford

The biological responses that result from harvesting treatments are critical to the postharvest management of all resources on the site. Harvesting prescriptions are in fact specified to achieve particular responses that are considered desirable, and to avoid undesirable responses. Study site harvest levels of 33, 66, and 100 percent basal area removal allowed the evaluation or prediction of the biological responses that could be expected over a wide range of prescriptions in lodgepole pine. Responses of concern include changes in basic site attributes such as moisture, temperature, and soil composition, resulting changes in tree and understory vegetation composition and growth, and stand predisposition to insect, disease, or physical damage. Information discussed in this section describes various predicted consequences of alternative harvesting prescriptions in small lodgepole pine.

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EVALUATING EXPECTED THINNING RESPONSE AMONG SMALL-STEM LODGEPOLE PINE STANDS //

Dennis M. Cole

ABSTRACT: Expected growth and yield response and which stands to thin are important considerations for managers of overstocked, small-stem lodgepole pine stands. These considerations were examined for five stands selected as representative of the small-stem management problem in lodgepole pine. The stands were compared with computer projections of growth and yield development across many decades, considering natural stand development versus nominal 33 percent and 66 percent basal area removal through low thinnings. Although useful for evaluating potential improvement in total and merchantable yields and product potentials, the stand projections gave inconsistent results in determining thinning priorities. Two other formal approaches were evaluated. Results from the three formal approaches were compared with a subjective approach based on a composite of commonly accepted biological criteria of stand and site conditions. The Thinning Response Index provided rankings that were consistent with those from the composite of stand and site criteria generally accepted as influences on stand vigor and growth.

INTRODUCTION

Overstocked, small-stem stands like those studied in the Systems of Timber Utilization for Environmental Management Research and Development Program of the Intermountain Research Station occur in great number over large acreages throughout the range of lodgepole pine (Pinus contorta var. latifolia Dougl.). Two questions almost always asked by foresters in the lodgepole pine region about stands like these are: (1) What yields can be expected from thinning or not thinning a specific stand, and (2) what is the relative potential for biological response to thinning among a number of stands?

The first question is usually addressed by reference to variable-density yield tables, or by making a specific projection for the stand in question with a computer program such as RMYLD (Edminster 1978). The second question has usually been addressed by ranking stands subjectively after viewing them and reviewing some stand statistics such as age and stand density. In this paper I address both questions.

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The first question was examined by using stand projections from the northern version of RMYLD (Cole and Edminster 1985). The second was considered by comparing three formal approaches for setting priorities for thinning with a subjective approach based on a composite of class rankings of factors commonly accepted as measures or indicators of stand and site condition. The subjective ranking was used in the comparisons instead of actual stand response, because response data are not yet available. Priorities identified by the different approaches were evaluated for biological consistency by a large number of foresters during a field visit to the stands to evaluate thinning response expectations.

METHODS

Five stands in the Phillipsburg Ranger District, Deerlodge National Forest, were selected to evaluate thinning response expectations for small-stem lodgepole pine. These were the same stands selected by workshop organizers for field visits, because they were considered representative of the small-stem management problem in lodgepole pine. Stand names were: Corduroy Creek East, Corduroy Creek West, Corduroy Creek North, Rattling Gulch, and Echo Lake. From the control (unthinned) plots of each stand, average values were calculated for a number of stand characteristics that were useful for interpretive purposes or necessary for use in equations and models (table 1). Stand inventory procedures are described elsewhere in these proceedings by Barger.

To address the question, "What yields can be expected from thinning or not thinning specific stands characteristic of the small-stem problem?" stand development was projected by 10-year growth intervals to 160 years of age with the northern version of RMYLD (Cole and Edminster 1985). Prescriptions examined were: no thinning, thinning from below to remove 33 percent of the basal area, and thinning from below to remove 66 percent of the basal area. The second question, "What is the likely order of thinning response among stands?" was considered by comparing results of three formal approaches to those of a subjective procedure based on commonly used criteria for evaluating stand and site conditions. The three formal approaches were: (1) periodic volume growth in 30 years following 33 percent basal area removal by thinning from below, according to projections of the northern version of RMYLD; (2) the Deerlodge National Forest guidelines for setting priorities for precommercial thinning projects (Joy 1986); and (3) a thinning response index based on

Table 1--Pretreatment values of factors related to stand vigor and growth

Stand	Average of dominants and codominants			Trees per acre	Quadratic mean stand diameter	Basal area	Crown Competition Factor CCF	Stand density index
	d.b.h.	Age	SI_{100}					
	Inches	Years	Feet		Inches	Ft^2		
Corduroy Cr. E	5.33	88	78	2,750	3.83	212	303	492
Corduroy Cr. W	4.64	88	69	2,800	3.08	164	330	479
Corduroy Cr. N	3.44	88	70	7,200	2.13	173	489	600
Rattling Gulch	6.99	59	83	1,175	4.95	140	189	317
Echo Lake	3.78	88	70	5,850	2.45	214	479	616

a regression model for estimating edge-response to clearing, recently developed by Cole (1986, in press). The subjective procedure involved a composite of stand rankings for each of five stand characteristics commonly accepted as either biological influences or indicators of stand growth potential.

Growth and Yield Projections

The five test stands were projected by decade intervals to 160 years for total volume yield, total volume mean annual increment (MAI), merchantable volume yield, and average stand diameter. Three of the five stands were chosen to illustrate relationships (figs. 1-4). To lessen cluttering of the graphs, only the stands with the lowest, highest, and intermediate stand densities were plotted (Rattling Gulch, Corduroy Creek North, and Corduroy Creek West, respectively). Relationships for the Corduroy Creek East and Echo Lake stands can be visualized from the figures by bearing in mind that the curves for Corduroy Creek East would generally fall very close to the Corduroy Creek

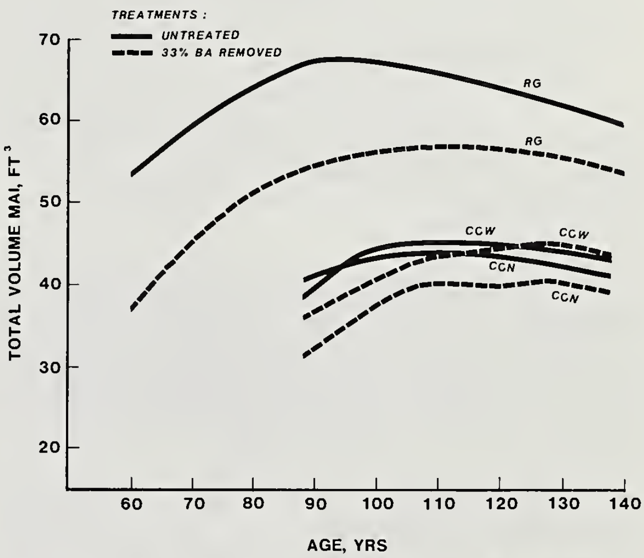

Figure 2--Projected net total volume mean annual increment (MAI), by age and treatment, at Rattling Gulch (RG), Corduroy Creek West (CCW), and Corduroy Creek North (CCN).

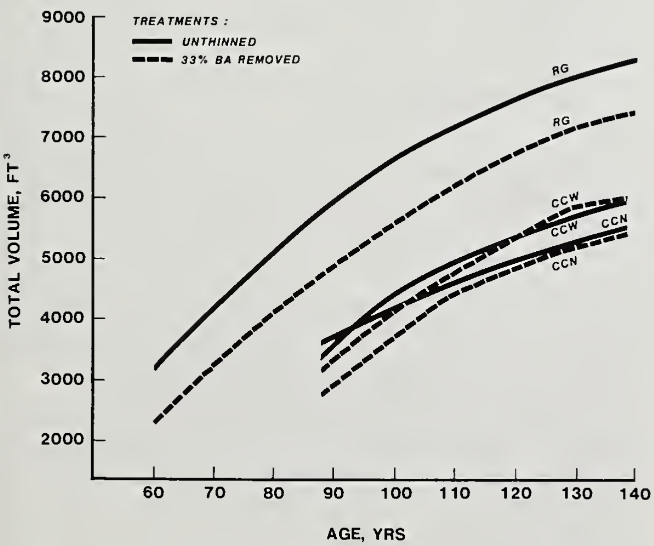

Figure 1--Projected net total cubic volume yields, by age and treatment, at Rattling Gulch (RG), Corduroy Creek West (CCW), and Corduroy Creek North (CCN).

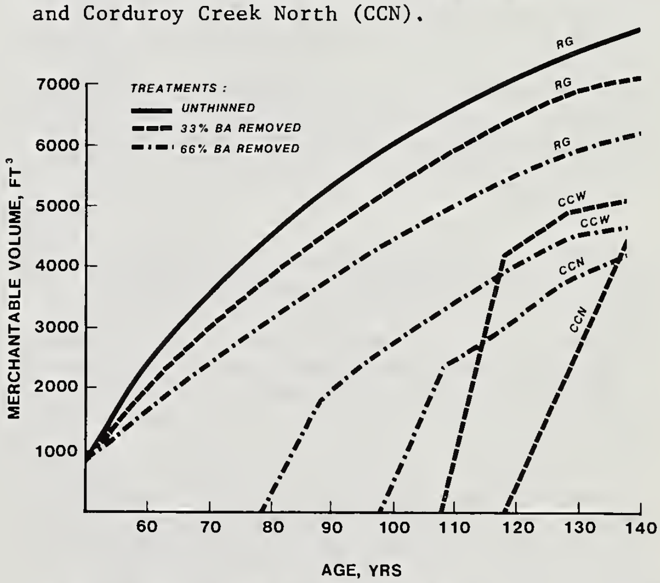

Figure 3--Projected merchantable cubic-foot volume (trees > 4.5 inches d.b.h., to a 3-inch top, by age and treatment, at Rattling Gulch (RG), Corduroy Creek West (CCW), and Corduroy Creek North (CCN).

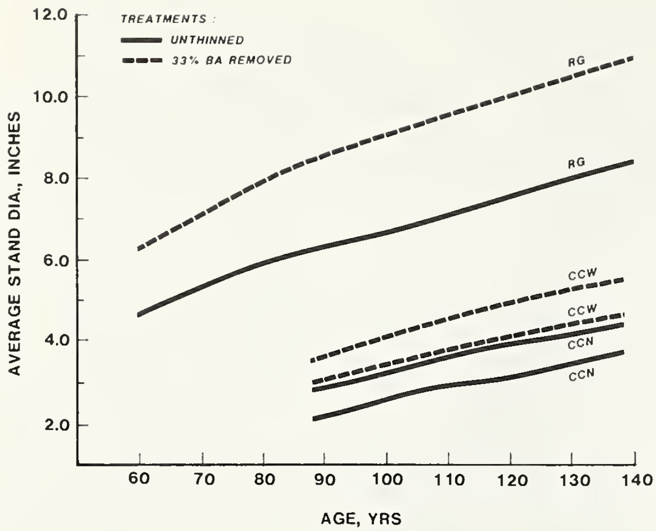

Figure 4--Projected average stand diameter in inches, by age and treatment, at Rattling Gulch (RG), Corduroy Creek West (CCW), and Corduroy Creek North (CCN).

West curves, but between them and the Rattling Gulch curves. The Echo Lake curves would fall very close to the Corduroy Creek North curves, but between them and the Corduroy Creek West curves. Differences between the stands were determined by reference to the tabular and graphical relationships provided by the projections.

Ranking Stands for Thinning

Stand Projection Approach--Projected periodic volume growth response to a fixed level of thinning was used as one approach for evaluating the relative response potential of the five test stands. The common thinning treatment assumed was a 33 percent reduction in stand basal area by low thinning. The amount of total volume growth, projected for the 30 years following thinning, was the criterion for evaluating the expected potential of the stands for thinning response relative to one another.

Deerlodge National Forest Approach--The guide developed for ranking precommercial thinning opportunities in the Deerlodge National Forest (Joy 1986) was next used to rate the test stands for thinning. This guide was considered because it incorporates many of the seldom-documented factors intuitively used by foresters for judging stands.

The guide appendix assigns scores for a combination of stand growth factors and operability factors such as aspect and slope. On the basis of the total score of all factors for each stand under consideration the guide classifies them into high, moderate, and low priority classes. Stands with scores of 20 to 28 points are considered high priority for precommercial thinning. Stands with scores of 13 to 19 are assigned moderate priority for treatment and those with scores of 9 to 12 are assigned low priority. Stands with scores of 8 or less are considered questionable and probably not scheduled for precommercial thinning. If a stand receives a zero score for any factor it is also considered to be disqualified from precommercial thinning consideration unless otherwise justified by another silvicultural analysis and prescription. On the basis of zero scores for age or average stand diameter, all five stands would be disqualified from precommercial thinning consideration. Nevertheless, the Deerlodge Guide was applied to the test stands to see if, aside from age and diameter, it provides a basis for discriminating between the stands in order of thinning priority.

Response Index Approach--A thinning response index (Cole in press), resulting from an indirect method developed by Cole (1986) for determining the relative order of expected thinning response among stands, was the third formal approach used to rank the test stands for thinning. This method is based on the response of dominant and codominant trees on edges created by clearing. This response was sampled in a wide range of stands varying in age, density, and site quality. Four alternative models based on this method explained 57 to 63 percent of the variation in response-to-clearing among dominant and codominant trees on the edges of study stands. Of these, a model explaining 63 percent of the variation in the dependent variable was selected. The model is:

$$\underline{Y} = -0.1221 + 0.1084\underline{D} + 0.0054SI_{100} - 0.0016\underline{A}$$

where

$\underline{Y}$ = common logarithm of the response of dominant and codominant edge trees, in square inches, in 10 years following clearing

SI_{100} = Site index at 100 years, as corrected for stand density (Alexander and others 1967)

$\underline{D}$ = Mean diameter of dominant and codominant trees

$\underline{A}$ = Mean age of dominant and codominant trees.

Thinning response indexes were calculated for each stand by converting the model predictions of edge response from the logarithmic form to original units, and dividing them by an indexing constant (12.0) determined as a near-maximum value of edge-response observed in the original study. The primary reason for indexing the predictions from the regression model was to dissuade users from considering the regression model as a predictor of actual response to conventional thinning. The thinning response indexes of the five stands were ranked in order of descending values to provide the basis for setting priorities for thinning potential.

Composite Factors Approach--Five characteristics were subjectively ranked for each stand: age, site index, trees-per-acre, quadratic mean stand diameter, and stand density index (Reineke 1933). Each characteristic was treated as a factor and

given two to five discrete classes, or ranks, reflecting the ranges of values represented in the five stands. For example, age was given only two classes to reflect the two distinct ages involved in the test stands; trees-per-acre, quadratic mean stand diameter, and stand density index were given five classes to reflect the greater differences among the stands in these factors.

The stand ranks determined for each factor (from table 1 data) were required to be biologically consistent with the known influence of that factor on stand growth and vigor; for example, the youngest stand was given the highest rank for age relative to the other stands; but for stocking, the stand with the least trees-per-acre was given the highest relative rank and the stand with the greatest stocking was given the lowest rank in that factor. This procedure was used for each factor and the relative rankings were reviewed onsite by a large number of workshop participants, to assure consistency with common biological understanding of the factors. A composite priority was determined by summing the factor ranks for each stand and assigning highest priority for thinning to the lowest sum of ranks, second priority to the next lowest sum, and so on.

GROWTH AND YIELD RESULTS

The volumes removed by initial thinning of typical overstocked small-stem stands are usually merchantable only as pulpwood, chips, or small roundwood products such as grape stakes. Potentials for these products are discussed by others elsewhere in these proceedings. Only the Rattling Gulch stand was indicated by projections to yield merchantable thinning volumes (trees >4.5 inches d.b.h., to a 3.0-inch top).

The economic aspects of this recovery, ranging from one-half to two-thirds of thinning volumes, also are discussed elsewhere in these proceedings. With current utilization and economic conditions, even the merchantable thinning volumes in the Rattling Gulch stand would likely be uneconomic. Growth and yield benefits of thinning small-stem lodgepole pine stands will be determined predominantly, then, by growth following thinning. Total and merchantable net cubic stand volumes and tree size in the years following thinning are useful criteria for evaluating future yields from these stands.

Net Total Cubic Volume

Differences in projected total cubic volumes among the unthinned test stands are due largely to the differences in site quality and stand density among the stands (table 1). Thinning is projected to reduce net yields of total cubic volume for all age and stand density combinations represented by the test stands for the next 50 to 80 years (fig. 1). The greatest reduction due to thinning is seen to occur in the least densely stocked stand, Rattling Gulch.

Increasing the intensity of thinning further reduced the projected net volume yield of the test stands. In general, the 33 percent basal area reduction treatment initially results in net cubic volume yield reductions of about 20 to 25 percent in moderately and heavily overstocked stands (Corduroy Creek West and North), but after about 40 years net volume recovers to about the same level as the unthinned stand (fig. 1). Because the thinning resulted in fewer trees, the near-equal volume following the 33 percent thinning after several decades would obviously be due to the larger crop trees in the thinned stand.

Projected net total volumes for the 66 percent basal area removal treatment, however, did not recover to the unthinned levels within the projection period in moderately and heavily overstocked stands--nor will either thinning treatment in lightly stocked stands increase net volume growth, relative to the unthinned condition.

Mean Annual Increment

Projected net total volume at various ages is not well-suited to show rate of change in volume growth, but projected net total volume MAI shows this well (fig. 2). Net total volume MAI is higher in less densely stocked stands and is seen to peak earlier and at generally higher levels in the unthinned than in the thinned stands.

Both figures 1 and 2 reinforce the common knowledge that when total cubic volume is the yield criterion thinning has little benefit in increasing net total volume yield at rotation--unless stands are young (for example, <40 years) and stagnated.

Merchantable Cubic Volume

Thinning markedly influences yield, when size of trees included in the yield is considered. For total cubic stand volume of all trees >4.5 inches to a 3.0-inch top, thinning is projected to produce appreciable merchantable volume yields in moderately (Corduroy Creek West) and severely (Corduroy Creek North) overstocked stands, where no merchantable yield occurs in the next 50 to 60 years without thinning (fig. 3).

At Rattling Gulch, stand density effects are minimal, thus most trees in even the unthinned stands at present are above the merchantability limits chosen for evaluation. If high enough merchantability standards (less utilization of small trees) were considered, then modest thinning intensity at Rattling Gulch would also be expected to show higher projected yields than the unthinned stand, after perhaps 40 to 50 years.

Average Stand Diameter

Average stand diameter (sometimes called quadratic mean stand diameter) is a useful characteristic for comparing growth responses among stands and treatments. Average stand diameter relates

especially well to product-size and value implications of stand development. Thinning increased the projected average stand diameters of test stands (fig. 4).

By observing the increase in the intercept for the thinned treatments of each stand in figure 4, when compared to the intercept for the unthinned stand, it is clear that most of the increase in average stand diameter from the thinnings resulted from the removal of smaller stems in the projected low thinnings. Nevertheless, by observing the increase in the slopes of average stand diameter over age of thinned versus unthinned stands, it is seen that projected thinnings in each of the test stands predict modest increases in the average diameter growth of the residual stand.

If the younger stand (Rattling Gulch) had been much more heavily stocked--or if the more heavily stocked stands (Corduroy West and Corduroy North) had been much younger--the growth in average stand diameter would have been predicted to be considerably greater; the slope of the curves in figure 4 would show greater divergence.

RESULTS FOR THINNING PRIORITY APPROACHES

Stand Projection Approach

Results of the stand projection approach to ranking stands for thinning are shown in table 2. The youngest, least-dense stand on the best site (Rattling Gulch) is expected to respond with the most periodic total volume growth and hence receives the highest indicated thinning priority.

Table 2--Thinning priorities according to projections of 30-year volume growth following thinning[1]

Stand	Periodic volume growth in total ft^3	Indicated thinning priority
Corduroy Cr. E	1,990	4
Corduroy Cr. W	2,080	3
Corduroy Cr. N	1,920	5
Rattling Gulch	2,690	1
Echo Lake	2,120	2

[1]Assumed 33 percent basal area removed from below.

The relative expectations for the other four stands are less distinct, because they vary from one another by only 200 ft^3 of volume growth; nevertheless all stands were given an indicated thinning priority or ranking, as shown in the last column, based on the magnitude of their projected periodic volume growth. The thinning priorities (rankings) in table 2 will be discussed further in comparison with the other approaches to ranking the stands for relative response to thinning.

Deerlodge National Forest Approach

Thinning priorities according to the Deerlodge Precommercial Thinning Guide are shown in table 3. There was relatively little difference in scores for most factors among the test stands, and the total scores for all five test stands varied by only one point. With the exception of the disqualification of all stands for precommercial thinning on the basis of zero factor scores, all test stands would have rated a moderate thinning priority. Noting the total stand scores in table 3, it is evident that the Deerlodge Guide did not distinguish between the thinning priorities of Rattling Gulch and the other stands, as did the growth projection approach summarized in table 2.

Response Index Approach

Stand values of the Thinning Response Index resulted in a distinct separation of several of the five test stands in terms of expected thinning response (table 4). By this approach, the Echo Lake and Corduroy Creek North stands showed nearly the same Thinning Response Index (0.25 versus 0.27) and would be considered to have essentially the same priority for thinning. This is shown in table 4 by a thinning priority of 4(a) for Echo Lake and 4(b) for Corduroy Creek North.

Composite Factors Approach

Ranking of the test stands by the subjective composite factors approach also resulted in a distinct separation of several of the stands (table 5). Like the response index approach, the composite factors approach rated the Echo Lake and Corduroy Creek North stands about the same in expected response to thinning. They were given thinning priorities of 4(a) for Echo Lake and 4(b) for Corduroy Creek North. The other three stands had considerable separation in their sum-of-ranks and thus were given distinct thinning priorities as seen in table 5.

Although the composite approach provides a rational basis for ranking these stands, it would likely prove insensitive for ranking many more stands than this. Insensitivity would occur when more than one stand received about the same composite sum of ranks--a probability that increases greatly with increasing number of stands in the comparison.

COMPARISON OF THINNING PRIORITY APPROACHES

Setting thinning priorities for the test stands by the approaches discussed here results in clear differences (table 6). Of the three formal methods--the volume growth projection, the Deerlodge National Forest Precommerical Thinning Guide, and the approach based on thinning response index--the priorities shown by the thinning response index were most consistent with those set by the composite of stand factors deemed to have biological relationships with stand growth and vigor. In fact as seen in table 6, results from these two approaches were the same.

Table 3--Stand priorities according to the Deerlodge National Forest Guide for ranking precommercial thinning projects

Stand	Age	Crown ratio	Average stand diameter	Stocking	Site index	Slope	Access	Dwarf mistletoe rating	Stand score	Thinning priority[1]
Corduroy Cr. E	[2]0	2	2	4	3	3	3	2	19	MOD[2]
Corduroy Cr. W	[2]0	2	2	4	2	3	3	2	18	MOD[2]
Corduroy Cr. N	[2]0	2	4	2	2	3	3	2	18	MOD[2]
Rattling Gulch	1	4	[2]0	2	3	3	3	2	18	MOD[2]
Echo Lake	[2]0	2	4	2	2	3	3	2	18	MOD[2]

[1]Stand score	Priority for precommercial thinning
<8	Very Low
9-12	Low
13-19	Moderate
20-28	High

[2]Zero score in one or more factors disqualifies the stand from precommercial thinning.

Table 4--Priorities of stands for thinning according to values of a Thinning Response Index based on predictions of edge response to clearing

Stand	Predicted edge response[1]	Thinning response index[2]	Thinning priority
	In^2		
Corduroy Cr. E	5.15	0.43	2
Corduroy Cr. W	3.99	.33	3
Corduroy Cr. N	3.05	.25	4(b)
Rattling Gulch	8.88	.74	1
Echo Lake	3.29	.27	4(a)

[1]Edge response = $10^{\underline{Y}}$, where $\underline{Y}$ = common logarithm of edge-response of dominant and codominant trees, in square inches, in 10 years following clearing; resulting from edge-response regression.

[2]Response index = $10^{\underline{Y}}/12.0$.

Table 5--Subjective thinning priorities for test stands by a composite of stand factors commonly interpreted as influences on growth and vigor

Stand	Relative stand rankings[1]					Sum of ranks	Composite priority
	Age	SI	Trees/Acre	QMSD	SDI		
Corduroy Cr. E	II	II	II	II	II	10	2
Corduroy Cr. W	II	III	II	III	III	13	3
Corduroy Cr. N	II	III	V	V	IV	19	4(b)
Rattling Gulch	I	I	I	I	I	5	1
Echo Lake	II	III	IV	IV	V	18	4(a)

[1]I = Highest; V = Lowest. SI = site index, QMSD = quadratic mean stand diameter, SDI = stand density index.

Table 6--Summary comparison of alternative methods of setting priorities for thinning lodgepole pine stands

Stand	Thinning priority by method			
	Composite of subjective stand factors	Volume growth projection	Deerlodge precommercial thinning guide[1]	Thinning response index from edge-response regression
Corduroy Cr. E	2	4	Moderate	2
Corduroy Cr. W	3	3	Moderate	3
Corduroy Cr. N	5	5	Moderate	5
Rattling Gulch	1	1	Moderate	1
Echo Lake	4	2	Moderate	4

[1]Strictly speaking, all test stands were disqualified from consideration for precommercial thinning because they exceeded the age maximum or average stand diameter minimum for this guide; however, the guide was applied to the test stands to see if it would indicate likely differences in thinning opportunities among the stands, aside from the thresholds for age and average stand diameters.

The Deerlodge National Forest Guide did not provide a basis for distinguishing between the test stands in thinning priority. The volume growth projection approach reversed the priorities of the Corduroy Creek East and Echo Lake stands, as compared to those from the composite factors and thinning response index approaches.

CONCLUSIONS

Growth and yield projections for small-stem lodgepole pine stands confirm, as is commonly believed, that thinning is necessary in most of these stands if merchantable yields and large trees are to be developed over a reasonable rotation. Increasing merchantable yields through thinning in these stands, though, is achieved at the expense of reduced total volume yields for periods of 50 to 100 years following thinning--the shorter periods associated with less-overstocked stands and less-intense thinning levels.

Only time will tell which of the approaches for determining thinning priorities will give the most accurate long-term results. At this point, I conclude that the composite factors approach and the thinning response index provided believable thinning priorities for the test stands. Of these two, setting priorities by thinning response index is likely to be more useful because it is not limited by the number of stands being considered. However, remeasurement of stand volumes will reveal the actual thinning response of the test stands and the relative performance of the methods considered here. Ten-year remeasurements should provide this completely objective evaluation.

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APPENDIX

PRECOMMERCIAL THINNING PROJECT RATING GUIDE (DEERLODGE)[1]

STAND ID: ______________

DATE: ______________

Age	Points	Score
0-15 years	0	
16-30 years	3	
31-50 years	2	
51-70 years	1	
71 + years	0	_____

Crown Ratio	Points	Score
Less than 25 percent	0	
25-40 percent	2	
41 + percent	4	_____

Average Stand Diameter	Points	Score
0-1.0 inch	1	
1.1-2.0 inch	3	
2.1-3.0 inch	4	
3.1-4.0 inch	2	
4.1 + inch	0	_____

Stocking (trees per acre)	Points	Score
0- 600	0	
601-1000	2	
1001-3000	4	
3001-6000	3	
6001 +	2	_____

Site Index (50-year base)	Points	Score
Less than 30	0	
30-39	1	
40-49	2	
50-59 or greater	3	_____

Slope	Points	Score
0-40 percent	3	
41-60 percent	1	
60 + percent	0	_____

Access	Points	Score
Roaded (access to stand)	3	
Less than half mile from road	2	
Half to one mile from road	1	
Over one mile from road	0	_____

Dwarf Mistletoe (lodgepole pine only)	Points	Score
*based on Hawksworth's six point rating system		
4 and over	0	
3	1	
1 or 2	2	
0	4	_____

GRAND TOTAL _____

[1]Developed by John Joy, silviculturist, Deerlodge National Forest

Stand and site conditions must be examined before using the rating guidelines to prioritize precommercial thinning projects. Existing stand and site conditions are then compared to the categories within each of the eight items, and scored according to the points listed. A rating of zero for any one item will generally be sufficient to eliminate a stand from future consideration unless a silvicultural prescription justifies treatment.

All individual item scores are added together to give a total score. The highest possible score is 28 points for lodgepole pine stands and 24 points for stands without lodgepole pine. On east-side forests only lodgepole pine has dwarf mistletoe, thus only those stands with lodgepole pine are rated on that item. Stands with scores of 20 to 28 points will be considered high priority for treatment provided that zeros are not recorded for any item. Stands with scores of 13 to 19 will be assigned moderate priority for treatment. Stands with scores of 9 to 12 will be assigned low priority. Those stands with scores of 8 or less will be considered questionable and probably should not be scheduled for precommercial thinning.

This ranking method is not intended to supplant silvicultural prescriptions but is intended to aid in the decision making procedure. The scores should enhance the prescription process and can be included as a portion of the diagnosis.

24½ EFFECTS OF WIND AND SNOW ON RESIDUAL LODGEPOLE PINE FOLLOWING INTERMEDIATE CUTTINGS

Jack A. Schmidt and Roland L. Barger

ABSTRACT: The physical characteristics of lodgepole pine make the species particularly susceptible to wind and snow damage when dense stands are opened by intermediate cuttings. Potential damage and residual stand losses must be considered when treatments are prescribed. This paper reports wind and snow damage and losses in 16 lodgepole pine units in which intermediate harvest cuttings were made. Four types of damage were recognized: lean, windthrow, snowbend, and breakage. Factors influencing the type and extent of damage included diameter of residual trees, residual stand density, and exposure to prevailing winds by adjacent clearcuts.

INTRODUCTION

Management of natural stands of pole-size lodgepole pine is a critical problem in the Intermountain West. Needed are greater age diversity, reduction of mountain pine beetle hazard, improved growth rates, and methods of meeting various nontimber resource objectives. Intermediate harvest cutting is an important tool for helping to meet these objectives. Lodgepole pine occupies almost 13 million acres of commercial forest land in the United States, ranging from California to Canada, and eastward to the eastern slopes of the Continental Divide. The species regenerates prolifically following intense fires, forming subclimax or transitional stands. As subclimax stands the species may persist on some sites indefinitely, retained by recurrent fire and isolation from other seed sources, and will likely be managed as a climax species (USDA Forest Service 1965). On other sites, lodgepole pine is a temporary occupant; invasion by reproduction of other species is significant.

Natural reproduction following fire is typically excessively dense, sometimes reaching hundreds of thousands of trees per acre. Dense stocking and relatively rapid juvenile height growth results in slender stems (fig. 1). Mature trees have been described as averaging "7 to 13 inches in diameter and 60 to 80 ft tall" (USDA Forest Service 1965).

Figure 1--The tall, slender growth habit of lodgepole pine trees in densely stocked stands makes the species vulnerable to wind and snow damage.

Lodgepole pine tends to self-prune in the dense stands, resulting in relatively short live crowns. The slender growth habit, with live crown concentrated at the top of the tree, makes the species especially susceptible to snowbend and breakage due to wind or snow loading.

Root development in lodgepole pine is variable and depends on soil characteristics. In general, a taproot is dominant during seedling and sapling development, but does not persist beyond the juvenile years (Cochran 1985). Lateral roots provide the major support after trees reach pole size. Because of the often shallow lateral root habit, lodgepole pine is usually considered to be vulnerable to windthrow (fig. 2).

Paper presented at Workshop on Management of Small-Stem Stands of Lodgepole Pine, Fairmont Hot Springs, MT, June 30-July 2, 1986.

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Figure 2--Shallow lateral root systems contribute to lodgepole pine susceptibility to windthrow.

Physical characteristics of lodgepole pine that predispose the species to wind and snow damage become particularly important when partial cutting or thinning treatments are proposed (Alexander 1975). Although clearcutting historically has been the dominant harvesting prescription for lodgepole pine, there is renewed interest in intermediate harvest cuttings. Thinning in pole-size stands has been shown to reduce susceptibility to mountain pine beetle attack (Amman and Safranyik 1985). Thinning in younger, vigorous pole stands also releases the residual stand to avoid stagnation and encourage accelerated growth rates. Retaining a residual stand on the site often helps meet wildlife habitat, esthetic, and other nontimber resource management objectives. This paper reports the effects of wind and snow on residual trees following different levels of intermediate harvest cutting in small-stem lodgepole pine stands in Montana.

SITE SELECTION

A major 5-year Intermountain Research Station research effort evaluated harvesting, utilization, and silvicultural alternatives in small-stem lodgepole pine. To address this problem, a series of studies was initiated to evaluate the economic feasibility and biological consequences of intermediate harvest cuttings in selected subsawtimber-size stands of lodgepole pine. One of these postharvest studies was the assessment of wind and snow damage to residual stands reported here.

Sixteen study sites were involved in the stand damage assessment, 15 of which were located in western Montana and one in southwestern Wyoming (fig. 3). Sites were initially selected to satisfy the sampling requirements for utilization and silvicultural study objectives, rather than stand damage study objectives. Consequently, such factors as position on the ridge, local wind patterns, and average snowfall were not site selection criteria. Nevertheless, the study sites represent a wide array of pretreatment stand density, tree size, and stand age. Represented are stands ranging from 3 to 7 inches in average diameter at breast height (d.b.h.), 1,000 to 8,000 green stems per acre, and 50 to 120 years in age. They are geographically distributed from the Wasatch-Cache National Forest to the Lewis and Clark National Forest (41° to 47° latitude), with study areas in four National Forests--Deerlodge, Gallatin, Lewis and Clark, and Wasatch-Cache.

Figure 3--Study sites were geographically dispersed from the Wasatch-Cache National Forest on the south, to the Lewis and Clark National Forest on the north.

TREATMENTS

Each study area was established and laid out to include two levels of intermediate harvest cutting--33 percent and 66 percent basal area (BA) reductions--plus an untreated control. Three of the study areas included a clearcut

treatment (fig. 4). Most study areas were 5 to 10 acres in size, with single treatment units ranging from 1.1 to 3.7 acres and averaging about 2 acres each. Permanently monumented sample points were established in each study area as a basis for pre- and posttreatment inventory. Applying constant basal area reduction treatments to stands of varying tree size and density resulted in a range of residual tree spacing on the different study areas. Residual stand stocking for the study areas is indicated in table 1.

Harvesting and utilization specifications for the study areas were established in an attempt to maximize product recovery from cut stems, and to leave a clean, undamaged residual stand for subsequent long-term evaluations of tree response and growth, as well as other biological responses. All cut trees 3 inches or more in diameter at the stump had to be removed from the unit (older dead excepted). Trees smaller than 3 inches could be left on site, but had to be slashed to lengths of 6 feet or less. Equipment was allowed to enter the stands only on designated skid roads that generally coincided with study area boundaries.

Movement of stems from stump to skid road had to be by hand or by line skidding. Restrictions on use of equipment in the stand generally served to avoid or reduce damage to residual trees. Physical contact between skidding equipment and residual trees, which can result in "root-springing" and reduced tree root strength, was avoided entirely. Line skidding occasionally pulled material against residual trees, exerting some lateral force against the tree at ground level; however, such occurrences were considered minimal.

ASSESSING DAMAGE TO RESIDUAL TREES

Damage assessment focused on wind and snow damage because of their potentially devastating effect within a stand soon after cutting.

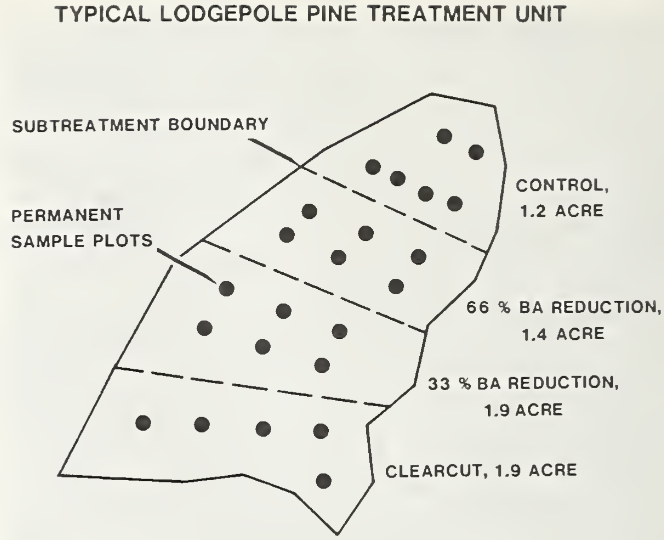

Figure 4--All study areas included a control and two intermediate cutting treatments. A few included clearcuts.

Twelve of the 16 study areas were treated during the period 1982-84, and were initially examined for damage to the residual stand in 1985. They were reexamined in 1986. The remaining four study areas were treated in 1985, and examined in 1986.

Four types of damage (fig. 5) recognized in the assessment were:

1. leaning trees
2. uprooted trees
3. snowbent trees
4. broken trees

The damage appraisal procedure involved a systematic examination of each treatment unit (control; 33 percent removal; 66 percent

Table 1--Residual stand stocking in green stems per acre, for all treatments

Study area	Control	33 percent BA removal	66 percent BA removal
		Number	
1. Spring Emery	3,535	1,500	943
2. Ballard North	4,028	1,149	250
3. Ballard South	1,929	936	407
4. Corduroy East	2,750	1,091	475
5. Corduroy West	2,800	1,943	614
6. Corduroy North	7,201	3,264	1,144
7. Rattling Gulch	1,175	400	241
8. Echo Lake	5,850	1,601	686
9. South Flat	1,650	1,036	429
10. Getcho	1,877	451	207
11. Reas Pass	1,332	402	190
12. Dry Fork East	4,967	1,327	544
13. Dry Fork West	3,976	1,578	600
14. Currie North	2,065	930	350
15. Cottonwood	2,200	932	321
16. Wet Park	4,620	701	315

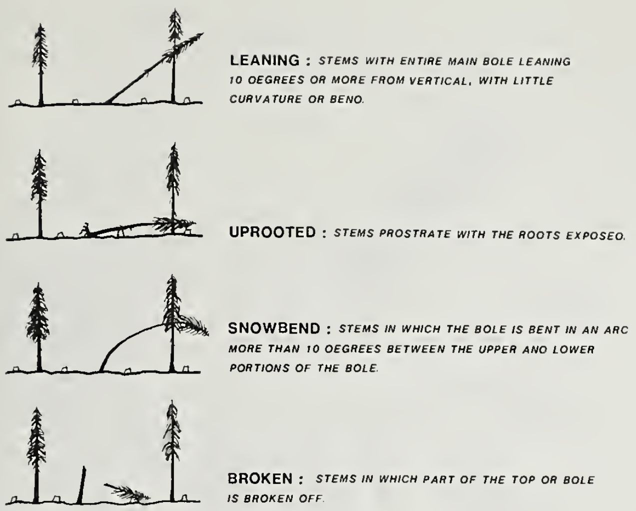

Figure 5--Four types of tree damage were used to evaluate effects of wind and snow on lodgepole pine.

removal) in a study area. All trees within each treatment unit were observed for damage. Damaged and down trees were marked to aid subsequent remeasurement, and the location of the tree was plotted on a field map of the unit. Observations and measurements for each damaged or down tree included:

- --type or category of damage (fig. 5)
- --tree d.b.h.
- --degree of lean, for leaning trees
- --magnetic azimuth of lean, or direction of fall for prostrate trees.

Assessment results reported here are necessarily limited to the relatively short postharvest time period of 1 to 3 years. Periodic assessments are planned that will evaluate damage over an extended time period.

Field data were edited and summarized for each study area and were subsequently summarized by treatment, type of damage, and tree diameter. Variables suspected of being significantly related to degree and type of damage included treatment prescription (level of thinning), diameter of residual trees, and exposure of the study area to direct wind.

RESULTS AND DISCUSSION

Type of damage varied considerably among study areas, but in total was relatively evenly distributed among the four classes.

Type of damage	Percent of damaged stems
Uprooted and down	30.0
Snowbent	29.7
Leaning	27.5
Broken stem	12.8
	100.0

Lean, snowbend, and uprooting each accounted for about 30 percent of the total observed damage, with breakage making up the balance. Contrary to a rather remarkable recovery from snowbend observed for young western larch (Schmidt and Schmidt 1979), the age and condition of these wind- and snow-damaged lodgepole pine make it highly improbable that they will ever recover from any of the four types of damage described in this study.

As expected, a strong relationship existed between tree d.b.h. and susceptibility to certain kinds of damage. A tree 7 inches in diameter, for example, is unlikely to snowbend; however, given the right wind conditions, it may be a likely candidate for uprooting. The following tabulation reflects observed relationships between type of damage and residual tree diameter.

Type of damage	Average d.b.h.
	Inches
Uprooted and down	4.8
Leaning	4.6
Broken stem	3.3
Snowbent	2.7

In general, the larger trees were more susceptible to wind damage (lean, windthrow); smaller trees were more susceptible to damage (breakage, snowbend) in which snow loading is a major factor.

Intermediate cutting of any kind increases the potential for wind damage in many timber types. With a typically shallow lateral root system, lodgepole pine can be particularly prone to wind damage following thinning (Alexander and others 1983). As the level of tree removal increases, leaving a more open stand, the stand becomes more susceptible to the effects of wind and the potential for damage increases (fig. 6). Damage observed in the inventoried treatments substantiates the relationship between level of basal area

Figure 6--Intermediate cutting treatments reduced basal areas 33 percent (left) and 66 percent (right).

reduction and degree of damage (table 2). Percent of residual trees damaged or uprooted ranged from negligible (0.04 percent) for the controls to 3.24 percent in the 66 percent basal area reduction treatment units. Uprooting of trees was the greatest single type of damage.

Table 2--Percent of residual stems damaged within each treatment, all study areas combined

Types of damage	Control	33 percent BA removal	66 percent BA removal
Leaning	<0.01	0.24	0.87
Uprooted	<0.01	.29	1.34
Snowbend	.02	.06	.48
Broken	.02	.36	.55
Total damaged	0.04	0.75	3.24

Although total damage to residual units was relatively small, it varied substantially among treatment areas. Damage ranged from 0 to more than 47 percent of the residual stems (table 3). The pattern of increasing damage with increase in basal area reduction generally remained true, further substantiating that relationship. Areas sustaining the highest levels of damage were also generally those in which treatments resulted in the widest postharvest tree spacing.

Winds in a geographic area typically follow a consistent pattern, which influences damage likely to occur (Alexander 1975). In all likelihood, storm fronts cause most of the damage. The dominating influence of wind direction on damage in the study areas is clearly demonstrated by plotting the average direction of lean or fall of damaged and down trees (fig. 7). As indicated, prevailing winds in the geographic area represented by sampled stands are from the northwest (approximately 315° magnetic azimuth). Direction of lean or fall in the study areas is essentially opposite that direction in all cases.

Unprotected exposure, such as that along a clearcut, and direction of wind in relation to the timber boundary have also been identified as principal factors influencing extent of wind damage (Alexander 1986). Clearcut treatments included on three of the study areas (as illustrated in fig. 4) allowed a limited assessment of their effect on adjacent thinned units. The juxtaposition of clearcut and thinned treatments created three different exposures to prevailing winds, corresponding roughly to 0°, 45°, and 90° to prevailing wind direction (fig. 8). The associated levels of tree damage in the exposed treatment areas were:

Angle between exposed treatment area and wind direction	Percent of stems damaged
0°	<1
45°	3
90°	47

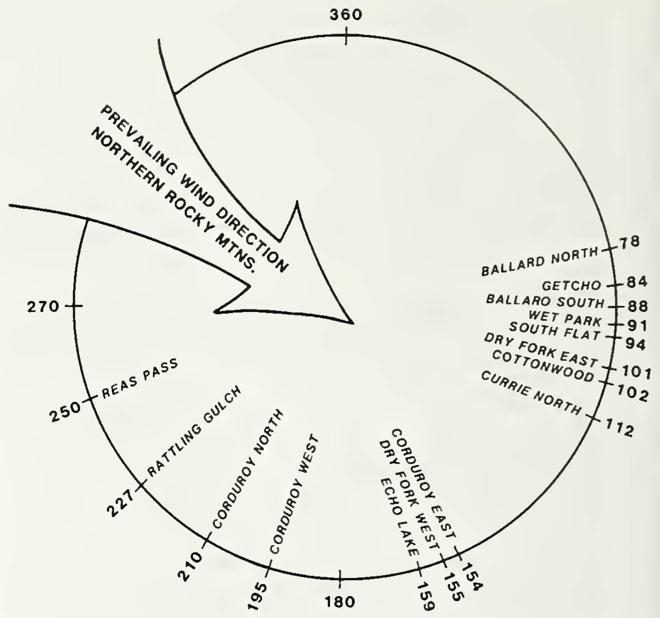

Figure 7--The relationship of average direction of lean or fall of lodgepole pine trees in relation to wind direction.

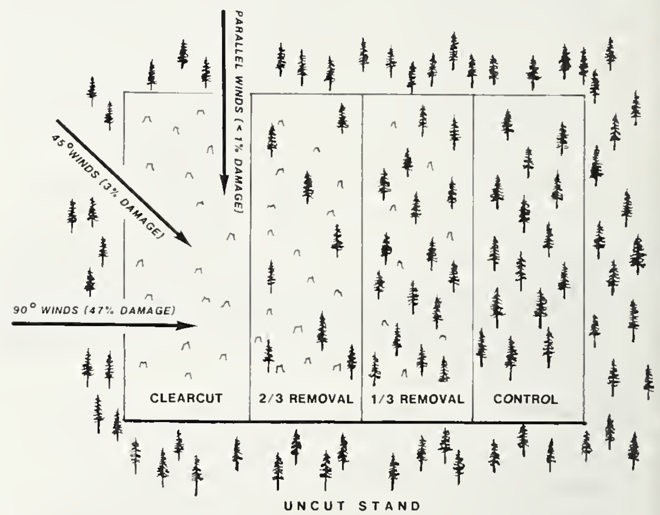

Figure 8--Direction of wind, in relation to the exposed face of treatment areas, affected the level of damage caused by wind.

The extreme influence of exposure to winds blowing across a clearcut at a 90° angle to the face of thinned areas is illustrated in figure 9. At the time of measurement, 30 percent of the stand left after cutting had blown down. Virtually all of the remaining stems exhibit significant lean away from the prevailing wind.

Table 3--Percent of residual stems damaged within each study area

Study area -treatment	Type of damage				Percent damaged
	Leaning	Uprooted	Snowbend	Broken	
Spring Emery					
-Control	0	0	0	0	0
-33 percent reduction	0	0	0	0.11	0.11
-66 percent reduction	0	0	0	.22	.22
Ballard North					
-Control	0	0	0	0	0
-33 percent reduction	0	0	0	.24	.24
-66 percent reduction	5.0	7.25	1.00	1.25	14.50
Ballard South					
-Control	0	0	0	0	0
-33 percent reduction	0	0	0	.36	.36
-66 percent reduction	0	0	0	0	0
Corduroy East					
-Control	0	0.03	0	0	.03
-33 percent reduction	0.15	.24	0.05	.24	.68
-66 percent reduction	.15	.15	0	0	.30
Corduroy West					
-Control	0	0	.03	.05	.08
-33 percent reduction	.06	0	.03	.24	.33
-66 percent reduction	.10	.10	0	.10	.30
Corduroy North					
-Control	0	0	0	0	0
-33 percent reduction	0	0	0	.23	.23
-66 percent reduction	0	0	.05	.16	.21
Rattling Gulch					
-Control	0	0	.08	0	.08
-33 percent reduction	1.73	1.54	.19	0	3.46
-66 percent reduction	.28	2.76	0	0	3.04
Echo Lake					
-Control	0	.04	0	.14	.18
-33 percent reduction	.06	.03	.26	1.50	1.85
-66 percent reduction	.58	.64	1.28	1.40	3.90
South Flat					
-Control	0	.04	.04	0	.08
-33 percent reduction	2.47	.48	.18	.18	3.32
-66 percent reduction	2.44	1.79	.33	.16	4.72
Getcho					
-Control	0	0	0	0	0
-33 percent reduction	1.48	.49	0	.86	2.83
-66 percent reduction	3.93	1.21	.30	0	5.44
Reas Pass					
-Control	0	0	0	0	0
-33 percent reduction	.19	.76	.19	.19	1.33
-66 percent reduction	0	2.17	0	0	2.17
Dry Fork East					
-Control	0	0	0	0	0
-33 percent reduction	0	0	.24	.65	.89
-66 percent reduction	0	.17	2.51	2.34	5.01
Dry Fork West					
-Control	0	0	.06	0	.06
-33 percent reduction	0	0	.05	.20	.25
-66 percent reduction	.28	0	1.53	1.81	3.62
Currie North					
-Control	.04	0	.30	.19	.53
-33 percent reduction	0	0	.18	.45	.63
-66 percent reduction	0	0	.66	0	.66
Cottonwood					
-Control	.02	0	0	0	.02
-33 percent reduction	.12	.04	0	.12	.28
-66 percent reduction	.32	.11	0	0	.43
Wet Park					
-Control	0	0	0	0	0
-33 percent reduction	2.57	.57	0	.10	3.24
-66 percent reduction	16.10	30.16	0	.91	47.17

Figure 9--The intermediate cutting area (foreground) adjoins a clearcut and is oriented directly (90°) into the most common wind direction. Windthrow and lean are severe.

CONCLUSIONS

Intermediate cuttings in younger, overstocked lodgepole pine stands are likely to be of continuing interest to land managers. Any consideration of silvicultural prescriptions should include careful evaluation of the possibility of wind and snow damage to the residual stand. The conclusions of this study should be helpful in such evaluations.

Conclusions supported by results of this study include:

1. Intermediate cutting does not necessarily mean that extensive wind and snow damage will occur. Relatively little wind and snow damage was observed after 3 years in this study--the only significant amounts being associated with those intermediate cuttings that were subjected to winds sweeping across adjacent clearcuts.

2. The intensity of intermediate cutting influenced the amount of wind and snow damage only modestly, with greater damage associated with heavier cutting.

3. Size of residual trees was associated with the type of damage that occurred; larger diameter trees suffered more lean and windthrow, and smaller trees more snowbend and breakage.

4. The position of intermediate cuttings in relation to adjacent clearcuts and wind direction appeared to be the factor most closely associated with the wind damage recorded in this study. If wind damage is to be minimized in intermediate cuttings adjacent to clearcuts, exposure to winds should be minimized by positioning intermediate cuttings upwind of clearcuts or limiting angle of exposure of stand edges to expected wind direction to less than 45°.

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WATER STRESS RESPONSE AFTER THINNING LODGEPOLE PINE STANDS IN MONTANA

Steven W. Running and Bryan L. Donner

ABSTRACT: Seasonal development of leaf water stress in thinned stands of lodgepole pine (Pinus contorta var. latifolia Engelm.) was compared to adjacent controls at three sites in Montana. Each stand was thinned to varying densities in the fall of 1982 or spring of 1983. Predawn leaf water potential measurements were taken monthly in the summers of 1983 and 1984 using the pressure chamber to determine plant water stress differences between thinned and unthinned stands. Late summer leaf water potential was significantly higher (0.17 to 0.35 MPa) in the thinned stands than in the controls. Computer simulation using the DAYTRANS/PSN ecosystem model suggested that 21 percent greater seasonal photosynthesis could occur in these trees as a result of the approximately 0.3 MPa higher plant water potential measured and additional radiation available to remaining trees. Based on estimated carbon budgets, this additional photosynthate could substantially increase the amount of carbon allocated to stem growth in these trees.

INTRODUCTION

Lodgepole pine (Pinus contorta) sites in the Northern Rocky Mountains typically are dry during late summer because of long periods with little precipitation. Thinning may improve site-water relations by reducing total stand transpiring surface area and live root density within the soil, thus increasing available water for residual trees. Canopy interception is also reduced, allowing a greater amount of rainfall to reach the soil surface. Sucoff and Hong (1974) reported an 18-year-old red pine (P. resinosa) plantation with greater leaf water potential and soil moisture content in a thinned stand than in an unthinned stand. Lopushinsky (1975) cited unpublished data by Seidel in Oregon that showed thinned lodgepole pine at midday had slightly higher moisture stress than an unthinned plot, attributed to increased exposure of the residual trees. An increase in soil moisture content following a thinning has been reported in lodgepole pine stands (Dahms 1971, 1973), red pine stands (Bay and Boelter 1963), and ponderosa pine (P. ponderosa) stands (Helvey 1975; Orr 1968).

Our study tested this hypothesis: Thinning overstocked, middle-aged lodgepole pine stands on water-limited sites in Montana will significantly reduce the water stress of the residual trees. We expected that crown ratio would also affect response. Further, reduced water stress would allow increased seasonal photosynthesis that would ultimately produce accelerated growth of the residual trees.

METHODS

Study Areas--The three selected study areas are referred to as Lubrecht (Lubrecht Experimental Forest), Rattling Gulch, and West Dry Fork. The Lubrecht site is located in the Garnet Range about 50 km east of Missoula. The stand originated from a postlogging fire in 1932 and grows on glacial lake sedimentary deposits. The Rattling Gulch site is in the Deerlodge National Forest, 25 km northwest of Philipsburg, MT. The stand grows on a midslope alluvial fan. The West Dry Fork site is about 6 km east of the town of Monarch in the Lewis and Clark National Forest in the Little Belt Mountains of central Montana. The stand is on a midslope Tertiary deposit of weathered limestone. The habitat type for the Lubrecht and Rattling Gulch sites is Pseudotsuga menziesii/Vaccinium caespitosum, and West Dry Fork is Pseudotsuga menziesii/Linnaea borealis (Pfister and others 1977).

These stands were thinned to varying densities in the fall of 1982 and early spring of 1983. Stand and site characteristics are summarized in table 1.

Basal area of all stands was very similar at 29 to 33 m^2/ha (table 1). Initial stocking densities were quite different for Lubrecht and Rattling Gulch at about 2,000 stems/ha and West Dry Fork at 12,000 stems/ha. Diameters and heights of trees at West Dry Fork are different than at the other two sites (table 2).

Sampling Procedures--The Lubrecht site consisted of one control and three treatments where varying amounts of basal area were removed. Rattling Gulch and West Dry Fork each had two thinning treatments in addition to the control. Ten sample trees were selected in each response unit. Response units are referred to as the control or by the percentage of basal area removed (for example, 37 percent and 48 percent at Rattling Gulch).

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Table 1--Study area stand and site characteristics

Feature	Study area: Lubrecht	Rattling Gulch	West Dry Fork
Initial leaf area index	5.1	5.5	6.3
Initial basal area (m^2/ha)	29.3	33.5	27.2
Basal area reductions (percent)	42	37	42
	50	48	78
	72		
Initial stocking density (stems/ha)	2,000	2,500	12,000
Residual stocking densities (stems/ha)	270	600	1,480
	560		
	1,090	990	3,900
Average stand age	49	60	58
Elevation (m)	1,250	1,700	1,600
Slope (percent)	5-15	0-10	30-35
Aspect	NW	W	NNE
Mean annual precipitation (cm)	45	46	50
Soil subgroup	Typic Eutroboralf	Typic Cryochrept	Typic Cryoboralf

Table 2--Average dimensional characteristics of sample trees

Study area and category	Characteristic: n	D.b.h.	Height	Crown width	Average live crown ratio
		cm	Meters	Meters	Percent
Lubrecht					
LCR: >55 percent[1]	20	20.4	16.1	4.0	62
<45 percent	20	12.9	14.7	1.8	30
Rattling Gulch					
LCR: >55 percent	15	18.6	15.7	3.2	62
<45 percent	15	12.6	14.6	1.3	39
West Dry Fork					
LCR: >55 percent	15	11.9	10.6	2.2	63
<45 percent	15	7.1	8.5	1.1	44

[1]LCR = contrasting live crown ratio. Used here to choose individual sample trees.

Individual sample trees were chosen primarily to fit two contrasting live crown ratio (LCR) categories of 55 to 75 percent and 25 to 45 percent. The categories were selected to determine if leaf water potential differences existed between trees with high and low leaf areas. The categories are referred to as the less than 45 percent category and the greater than 55 percent (table 2). Half of the 10 sample trees in the units fell in each category. Care was taken in sample tree selection to avoid extremes of shading or open areas.

Sample tree dimensions were measured before leaf water potential measurements began. Diameter at breast height (d.b.h.), total height, and height to the base of the live crown were measured using standard forest inventory equipment. LCR was calculated by dividing live crown length by total tree height. Increment borings for age were taken after all leaf water potential measurements were completed. Leaf area index of the stands before thinning was determined using regression equations based on d.b.h. developed by Gholz and others (1979) in Oregon. Average dimensional characteristics for each LCR category and sample sizes at the three study areas are presented in table 2.

Predawn leaf water potential measurements in 1983 were taken four times on a monthly basis beginning in June. All monthly data collection at the three sites was conducted within 5 days. An abbreviated sampling procedure was used in 1984 to verify results obtained the previous summer. Two sampling sessions were conducted at Lubrecht and West Dry Fork, and one session at Rattling Gulch, all similar to those conducted in 1983.

Each tree was sampled only once per session and no regard was given to canopy position when the sample twig was removed. A pressure chamber was used to estimate leaf water potential using standard techniques (Ritchie and Hinckley 1975).

To interpret the effect of precipitation on leaf water potential, meteorological data were obtained from U.S. Department of Commerce (1984) publications for the closest stations to each site. The main weather station for the Lubrecht Experimental Forest was 0.6 km from the Lubrecht study site. Forest Service weather stations are about 25 km southeast of and 90 m lower than the Rattling Gulch site and 5 km southwest of and 10 m lower than the West Dry Fork site.

An associated study conducted by other University of Montana School of Forestry researchers concerned seasonal soil moisture depletion at the Lubrecht site in 1983. These data were used to compare soil moisture depletion with leaf water potential response resulting from varying basal area removals. Nine neutron-probe access tubes were located in each response unit. Soil moisture (percent volume) was measured weekly from May 1 to November 8 at six depths ranging from 0.15 m to 1.52 m.

Statistical Analysis--Mean monthly leaf water potentials for each response unit were compared for statistical significance. Individual, one-tailed tests were performed to evaluate significant differences between the control and particular treatments, with a null hypothesis that treatment trees had no greater water potential than trees in the control treatments. A two-tailed test suggested significant leaf water potential differences between live crown ratio categories within each response unit on a given date. Significance was tested at the 95 percent confidence level. Analysis was conducted using the SPSSx Batch System.

Simulation Study--After observing water stress recovery of thinned stands we asked what effect this reduced stress might have on tree growth rates. Rather than waiting 5 to 10 years and observing growth release, we hypothesized that the reduced water stress and reduced canopy shading should allow greater seasonal photosynthesis to occur in these typically water-limited forest types. This hypothesis was most readily tested by computer simulation of photosynthetic response to our measured water stress data.

We used DAYTRANS/PSN, a daily resolution model of a tree water balance developed over the last 10 years (Running 1984a; Running and others 1975) that incorporates the photosynthesis equations in FAST-P, a model of conifer gas exchanged developed by the Swedish Coniferous Forest Project (Lohammar and others 1980). Complete documentation of DAYTRANS/PSN is available (Running 1984a), and a number of applications of the model similar to that in this study have been completed (Graham and Running 1984; Knight and others 1985; Running 1984b).

Two simulations were made using the DAYTRANS/PSN ecosystem model. First, a normal run was made to represent seasonal water stress and photosynthesis for a tree in the control stands. Second, the available rooting zone water supply was manipulated so that predawn leaf water potential was 0.3 MPa higher at the end of the summer, the general response shown by our field data. Leaf area removal of 50 percent for a thinned stand was programmed into the canopy radiation submodel, and seasonal water potentials and photosynthesis recomputed. Site conditions and the meteorological data required to run DAYTRANS/PSN were from the Lubrecht stand. However, these simulations were not meant to predict the response for any single study area, but rather to give a general interpretation of the potential growth response of a tree to reduced water stress and increased light availability.

RESULTS AND DISCUSSION

Leaf Water Potential and Thinning--Predawn leaf water potentials at all sites were usually lower in the controls than in any of the thinned units during both summers (figs. 1, 2, 3). In these figures, more negative (lower) leaf water potentials indicate greater water stress. At least one treatment produced significantly greater leaf water potentials than in the adjacent control for all measurement sessions except for West Dry Fork in June 1983 and Lubrecht in July 1983. In the Lubrecht stand, which is water-limited, when more water is made available, the remaining trees have reduced water stress. Tree water stress was proportional to basal area removed, with trees in the most dense stand having the greatest water stress (fig. 1). Very heavy rainfall in July caused leaf water potentials in all units to recover above -0.8 MPa with no significant differences between units. Drier August and September conditions decreased water potentials thus increasing water stress in all units, but most dramatically in the control. In 1984, trees in the control again had the greatest water stress.

Water potentials in the three units at Rattling Gulch responded similarly throughout both summers (fig. 2). The control and treatment water potentials were low in June but increased in July and August of 1983, due to rainfall of 14.5 cm during that period, double the historical average. The control water potentials were significantly less than the -48 percent unit in every measurement throughout the summer. The greatest difference between these two groups was 0.23 MPa in September. Basal area removals at Rattling Gulch were very similar, 37 percent and 48 percent, so both treated stands had similar water potential recovery. The one data set taken in July 1984 to verify the 1983 water stress recovery patterns showed a 0.2 MPa difference between the treatments and the control.

Of the three study areas, the West Dry Fork site consistently had the most significant differences between the control and the treatments (fig. 3). No early summer increase in leaf water potential occurred there in 1983 as it did at the other two sites. Precipitation in 1983 was about normal except for July. Precipitation was 120 percent above the normal of 4.37 cm in July 1983, which allowed leaf water potentials to stay unchanged

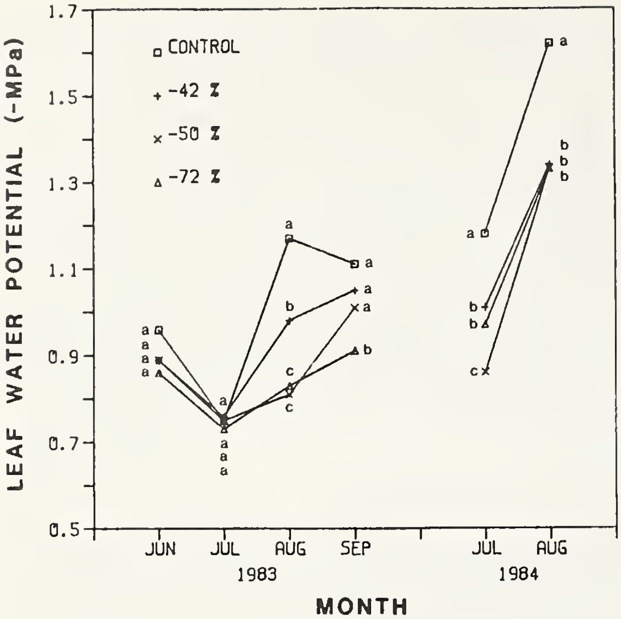

Figure 1--Seasonal trends in predawn leaf water potential by response unit, Lubrecht site. More negative leaf water potential indicates greater water stress. Treatments indicate percentage of basal area removed. Each point is the mean of 10 measurements. Means are considered significantly different (at 95 percent confidence level) if labeled by different letters.

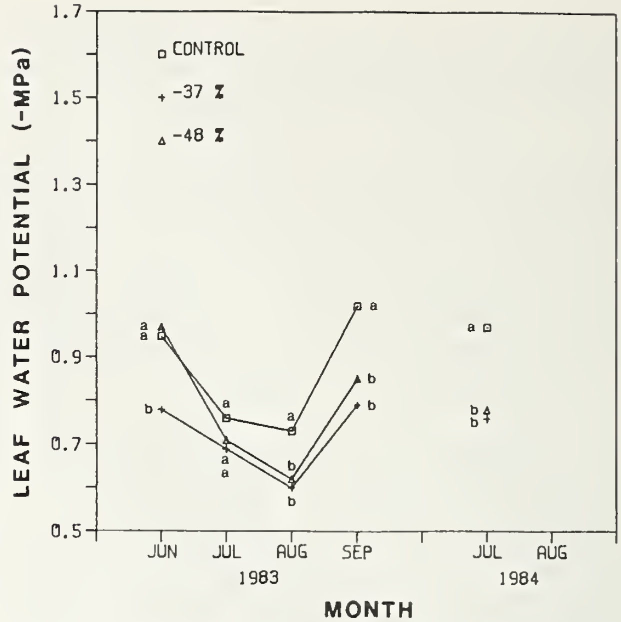

Figure 2--Seasonal trends in predawn leaf water potential by response unit, Rattling Gulch study site. More negative leaf water potential indicates greater water stress. Treatments indicate percentage of basal area removed. Each point is the mean of 10 measurements. Means are considered significantly different (at 95 percent confidence level) if labeled by different letters.

from June. However, July 1984 was extremely dry with only 0.41 cm total rainfall, which resulted in leaf water potentials averaging 0.36 MPa lower than July 1983. The remaining summer precipitation was relatively close to historical averages at the West Dry Fork site. The control stand had lower water potentials than the treatments in every measurement session except June 1983, and 0.35 MPa lower than the 78 percent unit for three of the six measurements. Water potentials increased in proportion to basal area removal in every case except June 1983.

These results appear to confirm the initial hypothesis. If more trees are removed the remaining trees have reduced water stress, thus the more room made available for the residual trees the more water is available. The significantly increased leaf water potential in lightly thinned stands (West Dry Fork) or stands thinned from low initial densities (Lubrecht and Rattling Gulch) indicates the sensitivity of the residual trees' water relations to reduced root competition.

The live crown ratio (LCR) did not appear to have a general effect on the ability of residual trees to recover predawn leaf water potential. Significant differences between the two LCR categories for a particular date and response unit were few and contradictory. The less than 45 percent LCR category sometimes had a greater mean leaf water potential than the greater than 55 percent LCR category; at other times the responses were reversed. We hypothesize that root/crown equilibrium was established in all trees in a stand before thinning, therefore increased soil moisture availability would not produce variable

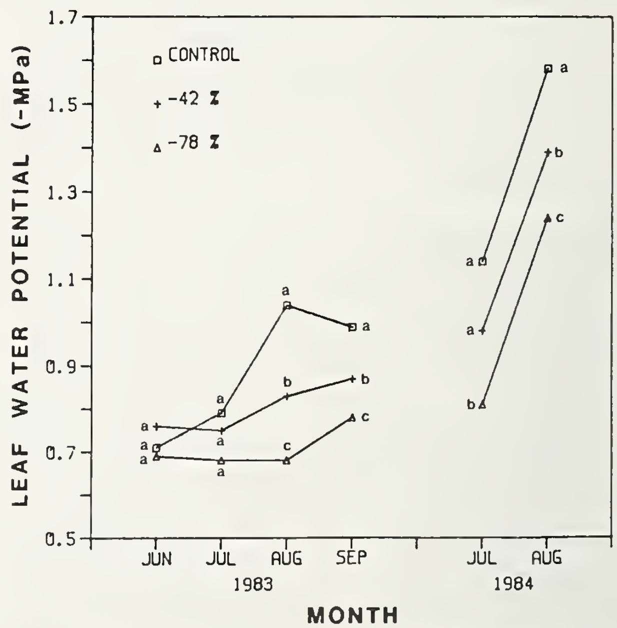

Figure 3--Seasonal trends in predawn leaf water potential by response unit, West Dry Fork study site. More negative leaf water potential indicates greater water stress. Treatments indicate percentage of basal area removed. Each point is the mean of 10 measurements. Means are considered significantly different (at 95 percent confidence level) if labeled by different letters.

recovery by different trees, as evidenced by the small variability in the pressure chamber data.

Soil Moisture and Thinning--To see how soil water availability is influenced by thinning, results from a companion study are shown in figure 4. Three points are notable:

1. Very little moisture was used from below 1 m (3 ft) in depth. This is interesting because these trees were starved for water and yet their roots did not go deeper to get more water.

2. The highest water depletion was in the zone from 0.3 to 0.5 m (1 to 1.5 ft).

3. Soil moisture depletion was roughly proportional to the amount of thinning--where more trees were removed less water was withdrawn from the soil.

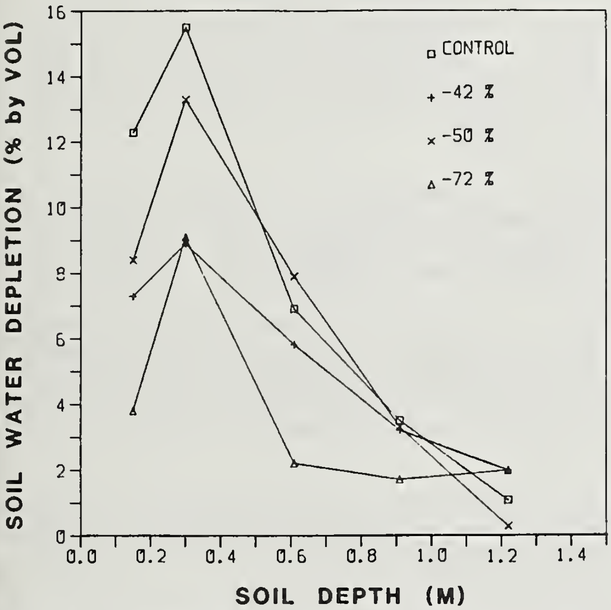

Figure 4--Seasonal soil water depletion, Lubrecht Experimental Forest. Depletion amounts were derived from the difference in soil moisture content on May 15 and September 24, 1983. Treatments indicate the percentage of basal area removed.

Simulation Results--The effects of thinning on leaf water potential and soil water depletion are interesting. But to answer the question of what this means to foresters in terms of growth, simulation of photosynthesis was used. An estimate of additional photosynthesis is about as close as we can get to growth without getting actual measurements.

The DAYTRANS/PSN model calculated a minimum predawn leaf water potential of -1.51 MPa at the end of the season for the control stand scenario, roughly the midpoint of the range of -1.18 to -1.62 MPa found for the 2 years at the Lubrecht site (fig. 5). The model calculated a seasonal photosynthesis of 89 mg CO_2/cm^2 leaf area for the control trees, and 108 mg CO_2/cm^2 for the thinned trees, or a 21 percent increase in overall photosynthate production for a tree in the thinned stand (fig. 6).

The prediction by DAYTRANS/PSN of 21 percent additional photosynthate availability initially does not seem very significant. However, in the

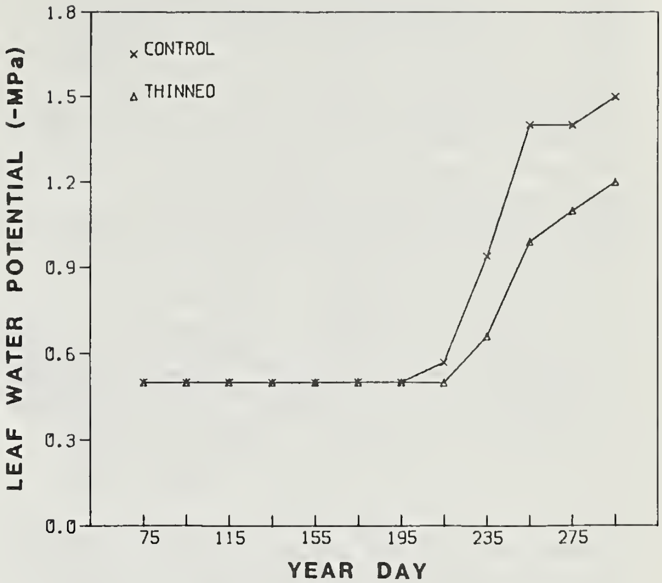

Figure 5--DAYTRANS/PSN simulation of the seasonal trend of predawn leaf water potential for a tree in a thinned versus unthinned stand of lodgepole pine. The thinned stand response was simulated by adding available rooting zone water (20 percent by volume) until the late season water stress was 0.3 MPa lower than in the control stand, calibrating model response to field data, and reducing LAI in the canopy radiation submodel by 50 percent. More negative leaf water potential indicates greater water stress. This calibrated response was then used to predict seasonal photosynthesis differences between thinned and control stands, shown in figure 6.

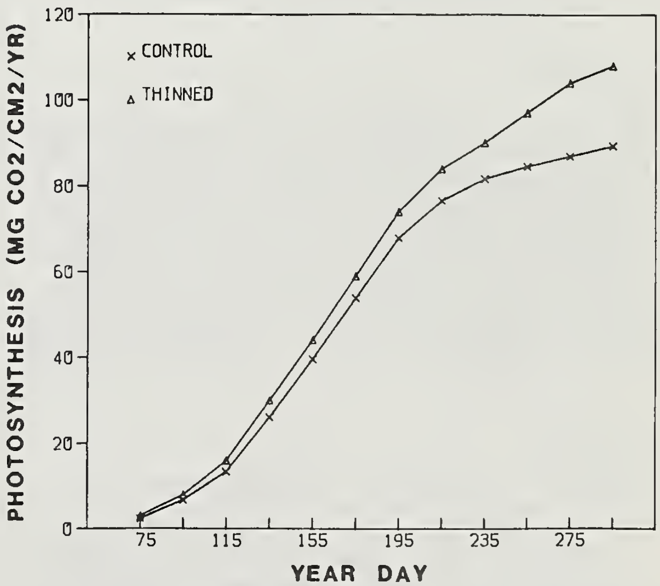

Figure 6--DAYTRANS/PSN simulation of the seasonal photosynthesis for a tree in a thinned versus unthinned stand of lodgepole pine. The thinned stand response was simulated by generating a 0.3 MPa recovery in predawn leaf water potential, which matches the observed field conditions, and reducing LAI by 50 percent in the canopy radiation submodel.

context of a total tree carbon budget as indicated by Agren and others (1980), a 21 percent increase in photosynthate availability may be quite significant, if the majority of additional carbon would go to stem growth. Stem growth is the last priority in carbon allocation by a tree, coming after respiration, root, and canopy growth demands are met. Added photosynthate may very well be allocated primarily to the stem, because other requirements have already been fulfilled. Agren and others estimated from integrating a variety of field data that only 8.5 percent of the annual photosynthate production of a single 14-year-old Scots pine (P. sylvestris) in Sweden was incorporated into stem growth. In their analysis, the most comprehensive tree carbon budget work we are aware of, respiration consumed 10 percent of annual photosynthate, and of greatest surprise, root growth used 57 percent of annual photosynthate.

If little of the predicted 21 percent additional photosynthate from our thinning response was needed by other parts of the tree, then the increase in photosynthate we predict could substantially increase the carbon allocated to stem growth. In reality, remaining trees opportunistically grow roots and crown into previously occupied area. However, the investment in that tissue probably is balanced by the return regained by additional tree leaf area producing even more photosynthate. Also, increased stem growth would require commensurately more growth and maintenance respiration. Hence, our analysis is only legitimate as an "instantaneous" response of the tree to reduced canopy light competition and increased available water supply. However, these predictions match the increases in tree growth efficiency (basal area growth/unit leaf area) found after thinning P. contorta by Waring (1983).

CONCLUSIONS

We think it is important to look at physiological responses when we do silvicultural research. We would also suggest that the new ecosystem simulation models when used correctly can provide some predictive capacity that we haven't had before. The prediction of thinning response reported here is an example of something we can do more often. Ecosystem models can help us predict before the fact, giving us more power to understand the potential consequences of our silvicultural activities.

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PREDICTING RESPONSE OF UNDERSTORY VEGETATION TO STAND TREATMENT: CONSEQUENCES FOR MULTIRESOURCE MANAGEMENT

Roger D. Hungerford

ABSTRACT: The procedure described here for predicting response of understory vegetation to treatment alternatives synthesizes ideas from published research on species survival strategies and growth characteristics. Seedling establishment equations are given for some tall shrubs. Height growth equations for four tall shrub species are also presented. An example of the procedure for three treatment scenarios is discussed to illustrate differences in the developing communities.

INTRODUCTION

Whether the purpose is to grow timber, enhance wildlife, manipulate water yields, enhance recreation, or provide grazing, land managers are in the business of managing vegetation. Silviculturists have spent much time and effort improving tree regeneration, partly by controlling competing vegetation. Wildlife managers concerned about declining populations have focused efforts on manipulating vegetation to provide cover and forage to improve wildlife habitat. A large part of range managers' efforts has focused not only on improving desirable forage plants but also on controlling undesirable plants.

In many cases multiresource management objectives and goals can be compatible, but they can also be competing. Whatever the objective, success or failure in achieving it often depends on knowledge about individual species characteristics. We also need to know how and why plants respond to various kinds of disturbances. And, understanding natural development and succession of plant communities is helpful for understanding how to manipulate the various species in the communities.

A number of regional models for plant succession exist (Arno and others 1985; Irwin and Peek 1979; Potter and others 1979; Stage 1973). Some of these models consider only the tree component (Potter and others 1979; Stage 1973), but submodels of the Prognosis Model (Moeur 1985; Wykoff and others 1982) include understory species occurrence and growth. Morgan and Neuenschwander (1985) give a conceptual model based on some causal factors for the cedar/clintonia (Thuja plicata/Clintonia uniflora) habitat type which describes understory development. Arno and others (1985) describe a classification model based on plant responses for four habitat types in western Montana. Keane (1985) used this to develop a simulation model.

Large acreages of even-aged, small-stem lodgepole pine stands occur in Montana. Many of these stands are old (over 80 years) and need treatment because they are overstocked. Also, large acreages are susceptible to attack by the mountain pine beetle. High mortality over many acres has already created a tremendous fire hazard, with a threat of accelerated mortality in many more stands. In addition, wildlife and watershed values are quite important in many of the stands. A major barrier to timber management in these stands is that the value of the products available is often insufficient to pay for the desired treatments.

Current research is directed toward making treatment of these stands more economical. Higher valued products are being developed, such as roundwood-based truss joists, which could make harvesting of many stands economical. New technologies and concepts for harvesting may also make removal of material more economical. Forwarding systems, walking machines with shears, large brush rakes, swathers, and other equipment could facilitate moving large amounts of materials more cheaply than present systems. Although few of these systems are in operation in our stands today, they are being used in other regions of the Country. If we assume that these or similar technologies may be used in the future, our management options will be greatly expanded.

Although new products and technologies will give us new opportunities, they will also bring new concerns. With new treatments, managers will not have experience in judging site and vegetation consequences. Without the benefit of long-term studies, we must base predictions on our understanding of how biological systems function. Using such knowledge can provide a reasonable basis for understanding how plants respond to disturbance. If vegetation response to a treatment can be predicted with some degree of certainty, then we should be able to evaluate consequences for other resources.

In this paper I propose a procedure for predicting species composition and growth of understory

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vegetation in lodgepole pine stands for 14 habitat types in Montana. The procedure is proposed as a method for evaluating effects on the understory vegetation of alternative stand treatments. The paper discusses the important components of the procedure and specifically deals with 28 species of plants. The procedure is a synthesis of some well-established ecological principles, new analyses of published data, and some existing approaches.

Equations to predict establishment of shrub seedlings of two species and height growth for four shrub species are presented. Tentative equations, based on published results, are also included for predicting biomass of low shrubs and herbs following clearcutting and for different overstory canopy levels. Following description of the procedure, an example is presented that illustates how it might be used to evaluate treatment alternatives. The procedure is presented as a preliminary approach that needs to be tested. The concepts and principles discussed could be used to expand the procedure to include other habitat types and additional species.

THE PROCEDURE

The procedure for predicting vegetation development is outlined in figure 1 and consists of two parts. Part one deals with predicting species composition of the initial plant community and part two with predicting the development rate of that community. To simplify the procedure, the species have been grouped (fig. 1), based on how they contribute to structure of the plant community. Low shrubs and herbs (3 feet or less in height) are typically important for their forage potential and as ground cover. Tall shrubs (more than 3 feet tall) are typically important to wildlife as cover and forage and for visual screening. Trees, including regeneration, are shown as part of the plant community, but are not part of the prediction process discussed here. Tree growth and development are handled adequately using other techniques. Models such as Prognosis (Stage 1973; Wykoff and others 1982) and LPPIM (Cole and Edminster 1985) are suitable and can be used for Montana lodgepole pine.

Information needed to use the procedure consists of site characteristics (habitat type), treatment characteristics (percent surface area disturbed, percent mineral soil exposed, depth of mechanical scarification, depth of lethal heat pulse from burning), vegetation characteristics (percent overstory canopy, pretreatment species, stocking density of tall shrubs), and species survival and colonization strategies. Outputs from the procedure are species composition, stocking density and height for each tall shrub species, and biomass for low shrubs and herbs. Based on average crown widths for tall shrubs, canopy shape is determined and structure of the developing community displayed. Other values such as wildlife hiding cover and visual screening can be derived from these values using other models (Lyon 1987).

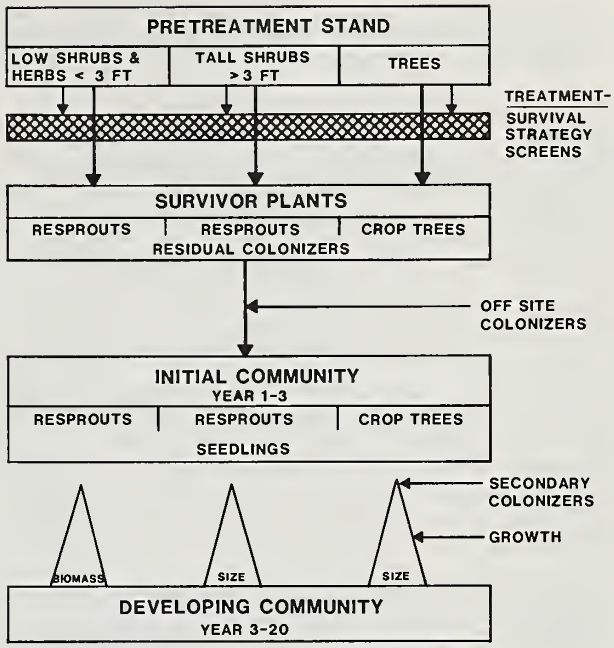

Figure 1--Diagram of procedure for predicting vegetation response on lodgepole sites in Montana in response to treatment. The procedure is keyed to survival and colonizing strategies of the plant species present in the pretreatment stand and adjacent stands.

PREDICTING THE INITIAL COMMUNITY

Two key concepts form the foundation of the first part of the procedure:

1. The majority of plant species that occur after treatment are present before treatment. Thus, if we know the pretreatment species composition we have a good start at predicting the posttreatment composition (Lyon and Stickney 1976; Stickney 1980, 1985, 1986a).

2. Survival and colonization strategies are known for many species. These provide the concepts for describing how species react to disturbances by sprouting, disseminating propagules, and establishing on new sites (Grime 1979; Lyon and Stickney 1976; Noble and Slatyer 1980; Rowe 1983).

Together, these two concepts allow prediction of surviving plants, and the addition of offsite colonizers and secondary colonizers following treatment.

Pretreatment Stand Data Needs

Following the conceptual model of Lyon and Stickney (1976) and Stickney (1986a), the best predictor of posttreatment species composition is the pretreatment species composition. As a minimum, data on species composition are needed for low shrubs and herbs and tall shrubs in the pretreatment stand. For the tall shrubs, a stocking

density is also needed. Data on abundance, such as canopy coverage, for low shrubs and herbs may be useful, but are not necessary.

An exhaustive species list is not needed, but the important species should be recognized. Importance can be based on a number of criteria, such as abundance, special management interest, forage importance, or some other measure. I have listed important species (table 1) based on abundance in habitats dominated by lodgepole. These species are those most likely to be present, based on constancy tables in Pfister and others (1977). Other species may need to be added by the user.

Needed species composition and stocking density data can be obtained using any number of standard sampling procedures (Mueller-Dombois and Ellenberg 1974; Pfister and others 1977; Stickney 1986a). A major concern for the user of this procedure is to select a sampling level with an acceptable error rate.

Using data from the pretreatment stand for the prediction procedure provides the maximum opportunity to select a preferred treatment based on expected vegetation development. However, the procedure can also be used after treatment to predict growth by sampling initial posttreatment vegetation. In either case, one starts the procedure with species composition and density data.

Treatment-Survival Strategy Screens

Species that exist in the pretreatment stand must pass through the treatment-survival strategy screen (fig. 1) to become part of the initial posttreatment community. Two major factors make up the "screen" through which species must pass. This screen determines posttreatment survival and abundance:

1. The type of treatment (fire, harvesting, seedbed preparation, and so forth) determines the depth and areal extent and the severity of disturbance.

2. Species attributes and survival strategy determine how individual species respond to disturbances.

The treatment applied, whether it is fire, harvesting, or both, interacts with the survival strategies of species to determine species survival. To predict what species pass through the screens, it is necessary to know the expected extent and depth of disturbance, values for which can be based on target values managers use in their prescriptions and their judgment based on past experience. The expected extent and depth of disturbance is then coupled with the survival strategy information in table 1 to determine survival for each important species. Because it is unlikely that 100 percent of the surface of any treatment area will be disturbed to the critical depth for most species, survival percentage by species can be evaluated.

A variety of survival strategy mechanisms exists among species common in lodgepole pine stands (table 1). These structures represent either the "bud bank," which allows for resprouting from various structures and depths, or soil- or crown-stored seed banks that are stimulated by treatment. Most of the root crown shrubs, those with rhizomes greater than 5 cm deep, and the geophytes (such as corms and bulbs) will resprout under quite severe conditions. For example, buds capable of resprouting on western serviceberry (scientific names are in appendix A) root crowns and rhizomes are located from the surface to greater than 5 cm below the surface. Thus, unless a treatment rips up the root crown and rhizomes, or provides a lethal heat pulse to greater than 5 cm deep, the plants are likely to survive the disturbance by resprouting. As indicated in table 1, some species (Scouler willow, Sitka alder, and fireweed) not only resprout but also establish from seed. Burns with deep ground char (Ryan and Noste 1985) can reduce sprouting (Rowe 1983), as can deep mechanical disturbances (Antos and Shearer 1980).

Species with soil-stored seeds (residual colonizers) can provide surprises in the initial community because there may not have been any living plants in the pretreatment stand. Seeds of these species may lie dormant for many years. Dormancy can often be broken by heat from fires or solar insolation on newly exposed surfaces. Black elderberry and elk sedge are typical species in the lodgepole type that follow this pattern. If residual colonizer species are present in adjacent disturbed areas, they are likely to be present after disturbance in other stands in the area.

Survivor Plants

Plants of species that make it through the treatment-survival strategy screens, plus the stored seeds (residual colonizers) that germinate and establish seedlings, make up the survivor plant component of the initial community. Some species from the pretreatment stand may be lost and the relative abundance of some species may be reduced. The process output for survivor plants is a species list and a density value for each tall shrub species; for low shrubs and herbs it is a list showing what species have survived.

This intermediate output should be viewed by the user and compared to the desired species composition. If important species are lost, or undesirable species have survived, the proposed treatment or treatments could be adjusted to achieve desired changes in composition. Adjustments in treatment prescriptions that alter percent of surface disturbed to critical depths for the concerned species will change survival. Treatment factors should be selected to maximize survival of the species important to the user, or mortality of unwanted species.

Offsite Colonizers

Seed dispersal from offsite sources is another important source of plants in the initial community (Morgan and Neuenschwander 1985; Stickney

Table 1--Summary of survival strategies, colonizer potential, and life history characteristics for some important understory species occurring in the lodgepole pine types near and east of the Continental Divide in Montana. Sources: Arno and others 1985; Bradley 1984; Fischer and Clayton 1983; Lyon and Stickney 1976; McLean 1969; Mueggler 1965; Pfister and others 1977; Stickney 1986a; Volland and Dell 1981

	Bud bank						Seed bank						
			Rhizomes and roots				Onsite			Offsite			Age to
	Root	Surface	Mineral	1.5-		Geo-	Second-	Residual		Initial		Second-	repro-
Plant species	crown[1]	stems[2]	surface[3]	5 cm	>5 cm	phyte	ary	Soil	Canopy	Near	Far	ary	duction
													years
Tall Shrubs													
Rocky Mountain maple	X						X		?			X	5-10
Sitka alder	X				X		X		X			X	5-8
Western serviceberry	X				X		X		?	X		X	7-15
Rusty menziesia	X						X						?
Scouler willow	X										X		?
Black elderberry	X							X					3-5
Low Shrubs and Herbs													
Common juniper							X				X	X	?
Utah honeysuckle	X										X		5-10
Prickly rose	X			?					?		X		3-5?
Baldhip rose	X			?					?		X		3-5
Russet buffaloberry	X				X			?	?				?
Snowberry				X	X			?	?		X		3-5
Globe huckleberry				X	X		X				X	X	10-15
Kinnikinnik		X						?		X			?
Twinflower		X					X			?	?		?
Shiny-leaf spirea				X	X		X			X		?	2-4?
Dwarf huckleberry				X			X				X	?	?
Whortleberry				X			X				X	?	?
Broadleaf arnica				X			X			X		X	1-2
Showy aster				X			X			X		X	1-2
Pinegrass			X	X			X			X		X	1-2
Elk sedge				X			?	X					3-5?
Fireweed				X	X	X	X				X		1-2
Glacier-lily						X	X			?		?	1
Strawberry		X					X				X		1-2
Beargrass			X	X			X			X			4-5?
Wheeler bluegrass				X			X			X		?	1-2?
Sidebells pyrola		X	X								X		?

[1]Somewhat massive structures from surface to several centimeters in depth.
[2]Stolons or stems at litter surface or in duff.
[3]At or near mineral aoil surface.

1986a). Seeds of these initial offsite colonizer plants originate in adjacent areas and take advantage of disturbed sites to germinate. Such seeds can be transported to the site by wind, animal, or water vectors, but usually they are small airborne seeds (Lyon and Stickney 1976). The importance of these offsite sources to the initial community varies with the seed availability, environment, topography, and with the condition of the seedbed provided by the treatment. Stickney (1986a) points out that the colonizer component is the most uncertain element in predicting the initial community because of the chance nature of immigration events. But a knowledge of the seed production characteristics and suitability of seedbeds can do much to reduce the uncertainty.

A number of the most abundant species are initial offsite colonizers (table 1), but only a few species (for example, fireweed and Scouler willow) can establish and make a big showing. The classification of species as initial offsite colonizers in table 1 is tentative. Specific information about the seeding habits of these species, particularly under natural conditions, is quite limited. Additional research is needed on seed dissemination and establishment requirements for many species.

For the low shrub and herb group it is probably sufficient, for this procedure, to assume that initial offsite colonizer species are likely to establish following most treatments where mineral soil is exposed. Fireweed, in habitat types where it occurs, is the only species in the low shrub and herb group that is likely to establish abundantly by colonizing from offsite. Others of these species may increase in abundance as surviving plants, set seed, and establish new seedlings. This process of secondary colonization will be discussed later.

Scouler willow is the only one of the tall shrub species in table 1 that functions as an initial offsite colonizer. I use Scouler willow as an example to illustrate an equation for predicting seedling density for an initial offsite colonizer. Scouler willow seeds are very small and short lived (Zasada and others 1983), making establishment very susceptible to weather and seedbed conditions. Seed is dispersed early in the spring (May to July) (Brinkman 1974), requiring a moist mineral soil seedbed for germination. For the habitat types considered in this paper, not much is known about Scouler willow seedling establishment. However, information from Stickney's (1980, 1986a, 1986b) studies in northern Idaho and western Montana can be adapted. In

these studies, seedling establishment and density were observed on permanent plots after burning treatments. At four different study locations the number of seedlings ranged from 0 to 1,300 per acre. The wide range of values for these locations suggests habitat type differences for establishment which may reflect seed production, weather, or site variations.

Predictions of seedling densities are based on the number of seed spots stocked. In this procedure, the number of potential seed spots is based on the average crown diameter measurements of Scouler willow from Stickney's data (1986b). Scouler willow crowns averaged 6.2 feet in width, thus covering 38 ft^2 of surface. If plants are evenly spaced, crown closure would be complete with 1,133 plants (43,560 ÷ 38.44) per acre. Any number of plants above 1,133 (spaced evenly) do not contribute much more to hiding cover, visual aspects, or other similar values; thus, I assume 1,133 potential seed spots per acre. To predict the number of spots stocked, two types of information are required: (1) the percent of potential seed spots with mineral soil exposed, and (2) the probability of any available spot becoming stocked based on habitat type differences.

For the most productive habitat types, I assumed that under normal conditions the probability of stocking potential seed spots with mineral soil exposed is 1.0 (100 percent). Establishment on less productive habitat types will be less than 1.0. Assuming that habitat type integrates site, weather, and seed production differences for establishment, judgments about probability on other habitat types can be made. Table 2 shows the probability values assigned to typical habitat types in the Montana lodgepole region. Values are based on judgment and constancy values for Scouler willow by habitat type (Pfister and others 1977). These values are consistent with density observations made by Stickney (1986b) and Lyon (1971) for comparable habitat types and treatments.

The final equation for determining the number of seed spots (S) stocked is:

$$S = PMq \tag{1}$$

where P is the potential number of seed spots per acre (1,133), M is the proportion of mineral soil exposure, and q is the habitat probability of any available spot becoming stocked.

Initial Community Composition

Survivor plants and initial offsite colonizers make up the initial community in the first 3 years following treatment. Based on Lyon and Stickney's data (1976), 70 to 86 percent of the plants in this initial community are from onsite sources (either survivors or residual colonizers) and 14 to 30 percent are from offsite seed sources. Sprouting potential for the survivors is not only a function of treatment and survival strategy type, but the age and vitality of individual plants in the undisturbed community (Gill 1977; Naveh 1975). More vigorous shrubs respond better. Although age and vitality are important, I have not included these factors because of the difficulty in aging plants and assessing vigor. Growth data used later include a range of conditions.

Following establishment of the initial community and addition of secondary colonizers that become established, the vegetation proceeds through

Table 2--Probability of seed spots becoming stocked with Scouler willow and Sitka alder, and potential number of plants per acre, by habitat type

	Scouler willow		Sitka alder	
Habitat type	Probability	Number per acre	Probability	Number per acre
PICEA/LIBO	0.18	204	0.7	793
ABLA/CACA	.08	91	.1	113
PSME/LIBO	.14	159	.4	453
ABLA/LIBO-LIBO	.18	204	.5	566
PICO/LIBO	.16	181	.5	566
ABLA/XETE	.12	136	.4	453
ABLA/LIBO-VASC	.09	102	.2	227
ABLA/CARU	.04	45	0	0
PSME/VACA	.06	68	0	0
ABLA/VACA	.12	136	0	0
PICO/VACA	.01	11	0	0
PSME/CARU	.01	11	.1	113
PSME/JUCO	.01	11	0	0
PICO/VASC	.02	23	.3	340
ABLA/VASC-VASC	.02	23	.3	340
TSHE/CLUN[1]	.40	453	1.0	1,133
ABLA/CLUN[1]	.14	159	.6	680
PSME/PHMA[1]	.01	11	0	0

[1]Habitat types sampled by Stickney (1986b).

annual iterations of development and mortality of these initial species.

Secondary Colonizers

Once the initial community is established, species called "secondary colonizers" continue to be added at a slow rate. The source for these plants can be onsite or offsite, and, although these species are a minor component (22 percent in Stickney 1986a), they are often important contributors to the community. Seedlings of these species must be capable of establishing in closed or partially closed communites. Although these characteristics are often attributed to climax species, some important seral plants also function this way.

The classification of species as secondary onsite and offsite colonizers in table 1 is based on limited available literature and observations (Stickney 1986b). Many of these species are known to function as secondary colonizers, but seedbed and environmental requirements need investigation. The potential for increasing in abundance needs further quantification.

For low shrubs and herbs, increases in abundance of secondary colonizer species will be included in the section on low shrubs and herb development. Some species (showy aster, broadleaf arnica, pinegrass, and fireweed) increase dramatically in abundance after some treatments (Fischer and Clayton 1983; Stickney 1986b). For the tall shrubs in table 1, all but Scouler willow seem to operate as secondary colonizers; however, Sitka alder is the only species that increases rapidly in density. Stickney (1986b) has observed colonizing seedlings of western serviceberry and Rocky Mountain maple, but their numbers are few and they grow slowly. I use Sitka alder as an example to illustrate an equation for predicting seedling density for a secondary colonizer.

Sitka alder functions as a secondary colonizer, in addition to a survivor, and over time greatly increases its density on a site. Sitka alder seed is not dispersed long distances, but most often falls within a 30-foot radius of the parent plant (Stickney 1986b). Surviving Sitka alder plants begin to flower and set seed from years 5 through 8. Often large numbers of seedlings become established about 8 years following a burn or other treatment. Apparently moss layers and litter from other vegetation do not inhibit establishment (Stickney 1986b), but the numbers of new seedlings decline after year 12.

Predictions of expected Sitka alder seedling densities can be made in a manner similar to that described for Scouler willow. I have assumed (1) the same number of potential stocking spots (1,133 per acre) based on a 6.2-foot crown width for the plants, (2) the probability of any available spot becoming stocked is based on habitat type, and (3) number and clumpiness of the surviving plants determine the potential stocking spots that seeds can be dispersed on. Habitat type probability coefficients in table 2 are assigned in the same manner as for Scouler willow.

Dealing with the clumpiness of the surviving plants adds some complexity. Assuming the seedfall around a surviving plant occurs in a 60- by 60-foot area, the influenced area is 3,600 ft^2. On an acre basis: 43,560 (ft^2) ÷ 3,600 (ft^2) = 12; thus 12 evenly spaced plants could potentially stock an acre (all 1,133 potential stocking spots). Each plant could potentially stock 94 stocking spots (1,133 ÷ 12).

The problem is that rarely will these plants be evenly spaced, so some measure is needed to determine the number of potential stocking spots influenced by the distribution of surviving plants. A key measurement needed for the surviving plants is the average distance between individuals. Given this measurement, one equation for three cases can be used to calculate the number of seed spots (S) expected to be stocked. The equation is:

$$S = NpMq \qquad (2)$$

where N is the number of 60- by 60-foot spots per acre occupied by survivors as determined below; p is the number of potential spots that could be stocked by one surviving plant; M is the proportion of mineral soil exposed by treatment; and q is the habitat type probability of any available spot becoming stocked.

When the number of survivors per acre (n) is less than or equal to 12, N is given by:

$$N = n \frac{(\bar{D}_M)}{(60)} \quad \text{for: } \bar{D}_M \leq 60 \qquad (3)$$

$$N = n \quad \text{for: } \bar{D}_M > 60 \qquad (4)$$

and when n is more than 12, N is given by:

$$N = \frac{\bar{D}_M}{\bar{D}_E} \qquad (5)$$

$\bar{D}_M$ is the mean distance between surviving plants and D_E is the mean expected distance between plants assuming an even distribution and given a plot area of 1 acre. $\bar{D}_E$ is calculated by:

$$\bar{D}_E = \frac{43,560}{n} \qquad (6)$$

Tests of these equations, based on hypothetical placements of survivors, showed that the results are at least reasonable. The equations provide one way to estimate the density and location of Sitka alder seedlings.

GROWTH OF THE INITIAL COMMUNITY

The developing community from succession years 3 through 20 is determined by growth of plants in the initial community and secondary colonizers. The aggregation of low shrubs and herbs, tall shrubs, and trees determines the structure of this developing community over time. It is the structure and biomass that to a large degree determine the value of the community for the variety of resource uses typically demanded of lodgepole stands. In this prediction procedure, growth of tall shrubs is expressed as height and crown development by individual species, while growth of low shrubs and herbs is expressed as biomass. These two groups will be discussed separately.

Tall Shrub Development

Stickney's data (1980, 1985, 1986b) provide the best opportunity to describe height development for Scouler willow, Sitka alder, western serviceberry, and Rocky Mountain maple. These data track height development for up to 18 years following wildfire or clearcutting and burning at five locations in northern Idaho and western Montana. Height growth equations resulting from other studies (Irwin and Peek 1979; Laursen 1984) are based on one-time sampling of many sites at different successional stages. Because the data indicate that resprouts and seedlings have different growth patterns, they will be discussed separately.

Shrub Resprouts--Observed growth patterns suggested that the data may fit the function described by the equation:

$$H = a(1-e^{-bt}) \tag{7}$$

where H is the height in meters, t is the number of years since disturbance, and a and b are coefficients.

Stickney's data were used in a curvilinear regression routine to obtain the least squares fit giving the best estimates for a and b. Two separate relationships were fitted: (1) potential height growth was evaluated using observations with no obvious height growth reduction due to snag falls, snow damage, browsing, and so forth; (2) average height growth was evaluated by including measurements with observed height damage.

Height growth is influenced by a variety of factors such as genetic capability, competition with other plants, mode of reproduction, site characteristics, weather, shade, time and others (Irwin and Peek 1979; Laursen 1984; Morgan and Neuenschwander 1985). These need to be accounted for in the equations. In the equation form given above, the coefficient a describes the asymptote of the curve, or the maximum height approached and b represents the growth rate, or the rate at which the maximum height is approached. Factors potentially influencing coefficient a and b include:

1. Genetic capability
2. Site characteristics that influence site capability
3. Overstory shading
4. Competition with other plants
5. Weather.

Some of these factors are easily represented, such as genetic potential which is represented by height of the tallest plants. Site characteristics and weather as they influence maximum height and growth rate are easily understood, but hard to assign values. I have chosen to use habitat types to represent site capability and weather effects on a and b because in theory habitat types integrate these factors. The concept of shade tolerance is well accepted and easy to understand, but not so easily quantified. Data are lacking to determine the effects of shade on the four shrub species considered here; thus, I use separate equations, one to describe a level of 80 percent overstory canopy and another to describe height growth in full sun. Any future data on shade effects could be used to develop an equation for shade, thus replacing the one level used here. Competition is also an easily understood concept, but it is difficult to quantify. In the equations that follow, I have assumed that typical levels of competition are represented in the data, eliminating the necessity to treat it as a variable. The resulting expanded equation form for resprout shrub height growth is:

$$H = gh(1-e^{-bht}) \tag{8}$$

where g is the genetic height potential and h is the habitat type correction for site.

The habitat type corrections for height growth development are shown in table 3. Corrections were chosen to represent site capability and climate, as these factors influence growth. Data on elevational ranges, precipitation, and temperature (Pfister and others 1977) were also considered when assigning the values for h to each habitat type. All values were benchmarked to the better sites studied by Stickney (1980, 1985, 1986b), ranging from 0 to 1.0, with 1.0 representing the best sites. Figure 2 shows how habitat type is expected to influence height growth rate and maximum height for Scouler willow resprouts. Rocky Mountain maple and western serviceberry are expected to follow a similar pattern. Sitka alder, however (table 3), does not seem to be influenced by habitat type. Sitka alder height growth data from TSHE/CLUN to ABLA/VASC (Lyon 1976, 1984; Stickney 1985, 1986b) show no differences between the two types. One might expect that on some habitat types growth should be slower, but evidence is lacking to verify that assumption.

Equations 7 and 8 and the coefficients for a and h shown in tables 3, 4, and 5 can be applied to typical Montana lodgepole sites. The coefficients given for a can be considered as the maximum potential height for these species. If the user has a better value for maximum height or one that is more realistic for the specific site, it can be substituted for the table values to calculate height growth.

Table 3--Height growth coefficients for tall shrubs by habitat type

Habitat type	Height growth coefficient[1]			
	SASC	ALSI	AMAL[2]	ACGL[3]
PICEA/LIBO	1.0	1.0	1.0	1.0
ABLA/CACA	1.0	1.0	[4]--	--
PSME/LIBO-CARU	.9	1.0	1.0	1.0
ABLA/LIBO-LIBO	.9	1.0	.9	1.0
PICO/LIBO	.9	1.0	.9	.9
ABLA/XETE-VAGL	.8	1.0	.8	.9
ABLA/LIBO-VASC	.8	1.0	.8	--
ABLA/CARU	.8	--	.6	--
PSME/VACA	.7	--	.9	--
ABLA/VACA	.7	--	.8	--
PICO/VACA	.7	--	.8	--
PSME/CARU	.7	1.0	.8	.7
PSME/JUCO	.6	--	--	.7
PICO/VASC	.5	1.0	.5	--
ABLA/VASC-VASC[5]	.5	1.0	.5	--
TSHE/CLUN-CLUN[5]	1.0	1.0	1.0	1.0
ABLA/CLUN-CLUN[5]	1.0	1.0	1.0	1.0
PSME/PHMA-PHMA[5]	1.0	--	1.0	1.0

[1]Coefficient to adjust height based on habitat type is applied to both coefficients in the height growth equation for resprouts and to the a coefficient for the seedling height growth equation.

[2]Coefficient is based on elevational gradient of habitat types, as suggested by Mueggler (1965).

[3]Coefficient is based on elevational gradient, as suggested by Laursen (1984).

[4]Species not likely to be present in these habitat types.

[5]Equations developed from data on these habitat types.

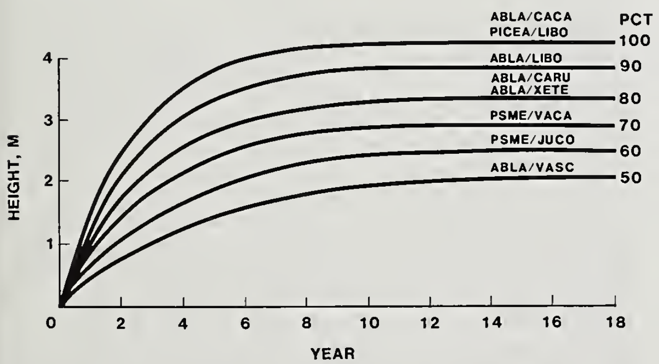

Figure 2--Habitat type effects on height growth are shown for Scouler willow for several habitat types. Reductions in height by habitat type are relative to growth for the best sites. The effect is similar for the other tall shrub species.

Results of the analysis to fit Stickney's data to the equation and evaluate the coefficients for a general fit to all sites are given in table 4. Based on r^2 and standard error of estimate values, the equation seems to represent height growth over all sites combined rather well. Figures 3A and 3B illustrate the least squares equation fit and actual data points describing potential and average growth of Rocky Mountain maple. Plots for other species are not shown, but are similar.

Coefficients for the equations describing growth under an 80 percent canopy (table 4) are all based on a few Scouler willow shrub resprouts in a dense lodgepole pine stand. These shrubs were dissected to determine age and annual height growth increments under an overstory. Growth measurements were then used to develop curvilinear regression coefficients. The reduction observed for Scouler willow growth in the shade compared to full sun was used to adjust full sun coefficients to the 80 percent canopy condition for the other three species. Figure 4 shows the height growth curves for all four species over a 16- to 18-year period following treatment. Potential, average, and shaded site curves are shown where appropriate.

Shrub Seedlings--Seedling establishment and growth is important for Scouler willow and Sitka alder, but is not a major contributor toward community development in the first 20 years for Rocky Mountain maple or western serviceberry. The procedure I followed for developing growth equations for Scouler willow and Sitka alder was the same as for the resprouts. Height growth patterns for these two species were found to follow a function of the form:

$$H = \frac{a}{1+be^{-ct}} \tag{9}$$

where H is height in meters, t is time since treatment and a, b, and c are coefficients.

Seedling height data (Stickney 1986b) were used to develop curvilinear regression coefficients. The coefficients for this equation are not as easily assigned biological meaning, but a represents the maximum height or genetic potential (g), as in equations 7 and 8. Both b and c influence the rate at which height growth approaches the maximum value. Habitat type correction for height growth can be made by adjusting the coefficient a and the equation becomes:

$$H = \frac{gh}{1+be^{-ct}} \tag{10}$$

where h is the habitat type correction coefficient and g is the genetic potential.

Height reductions were observed for seedlings, as they were for resprouts; therefore, I developed potential and average equations for both species. In addition, I developed an equation for dense seedlings of Scouler willow where 1,300 seedlings per acre were present. This situation represents a high degree of competition (fig. 4).

Coefficients from the analyses are shown in table 5. Good fits to this equation form are indicated by the r^2 values and the standard errors of estimate. Equations 9 and 10 seem to

Table 4--Coefficients for resprout height growth equations for four tall shrubs under different canopy conditions--potential and average growth

Species and overstory	Equation coefficients[1]							
	Potential				Average			
	a	b	r^2	SEE	a	b	r^2	SEE
Willow (SASC)								
No canopy	4.3	0.45	0.80	0.25	3.5	0.45	0.79	0.32
80 percent canopy	3.5	.15	.99	.05	2.3	.16	.98	.09
Serviceberry (AMAL)								
No canopy	3.2	.26	.84	.22	2.6	.33	.72	.27
80 percent canopy	2.6	.08	--	--	2.6	.08	--	--
Alder (ALSI)								
No canopy	4.5	.26	.92	.24	4.5	.10	.84	.33
80 percent canopy	3.6	.08	--	--	3.6	.08	--	--
Maple (ACGL)								
No canopy	4.6	.16	.83	.35	2.9	.17	.72	.27
80 percent canopy	4.6	.08	--	--	2.9	.08	--	--

[1]Equation form: $Y = a(1-e^{-bt}) = Y = gh(1-e^{-bht})$;
(h = habitat coefficient; g = genetic potential).

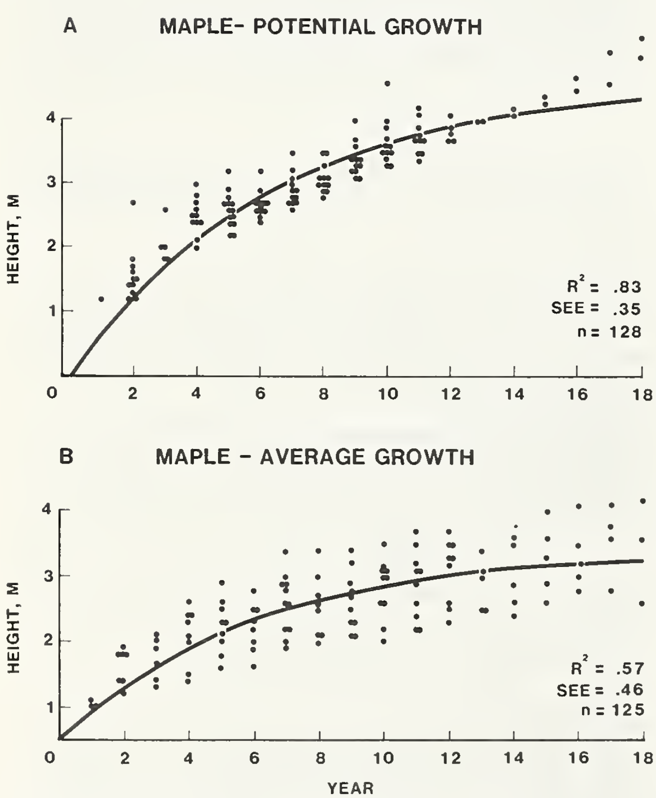

Figure 3--Equation fits for height growth of Rocky Mountain maple. (A) Curve is the least squares fit to the plotted data points for the potential height growth. (B) Curve is the least squares fit to the plotted data points for the average height growth. The number of observations and the equation statistics are given for both situations.

describe the growth patterns for Scouler willow and Sitka alder seedlings quite well. Growth, from the time of establishment, is initially slow (fig. 4). This initial period would seem to coincide with the period of root development. Growth rate increases after 4 to 6 years, with maximum heights approaching the height of resprouts by 16 to 18 years. Where Scouler willow seedlings were dense, growth rate was slower. Yet, eventually, maximum heights equivalent to resprouts may be reached, if plants are not shaded out first.

Height Growth Comparisons--Height predictions from Irwin and Peek's (1979) and Laursen's (1984) equations are compared in figure 5 with those presented here. I adjusted the variables to fit the conditions of Stickney's sites and represent the conditions Laursen used for total cover and stand basal area values. The treatment simulated for these runs was a clearcut and a burn. Laursen's equations for average height growth predict shorter plants, except for Rocky Mountain maple, than do my average height equations until about years 13 to 15 when the values are equal (Sitka alder excepted). For Rocky Mountain maple, Laursen's equations predict heights similar to my potential growth equation. In the case of Scouler willow, Sitka alder, and western serviceberry, Laursen's growth curves are much more linear over the growth period than my curves; thus, my equations predict much more rapid initial height growth.

Compared to Irwin and Peek's equations, equations developed here predict taller western serviceberry, shorter Scouler willow, and equal Rocky Mountain maple heights for average plants. The shape of the curves, with more rapid initial growth, is comparable.

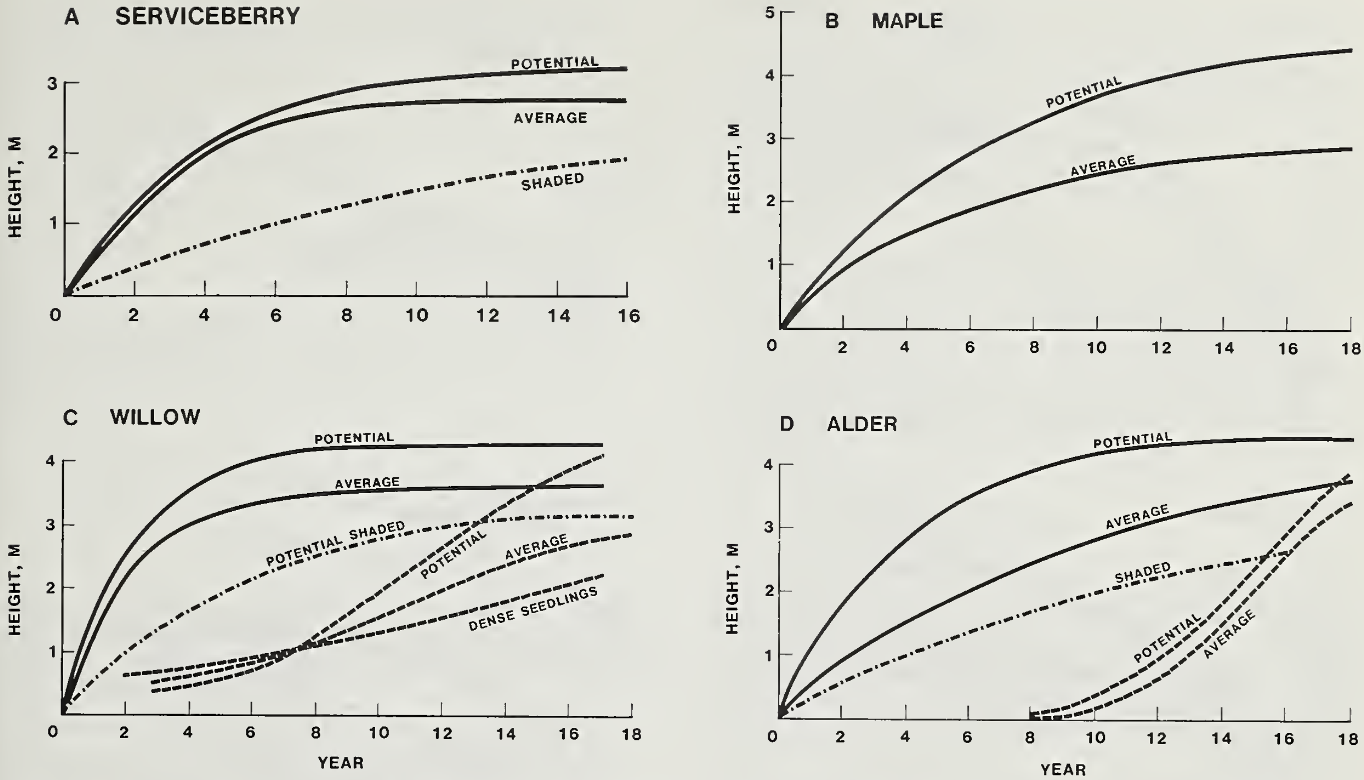

Figure 4--Height growth curves for western serviceberry (A), Rocky Mountain maple (B), Scouler willow (C), and Sitka alder (D). Curves are shown for potential and average growth in full sun and under shade for some species. Seedling growth curves are shown for willow and alder.

Table 5--Coefficients for seedling height growth equations for Scouler willow and Sitka alder--potential and average growth

Species and overstory	Equation coefficients[1]									
	Potential					Average				
	a	b	c	r^2	SEE	a	b	c	r^2	SEE
Willow (SASC)										
No canopy	4.7	33.7	0.31	0.97	0.16	3.4	14.0	0.24	0.82	0.30
Dense seedlings	5.2	11.7	.13	.95	.17	3.6	6.1	.08	.82	.13
Alder (ALSI)										
No canopy	4.9	23.4	.44	.98	.16	3.9	38.0	.54	.89	.33
Serviceberry (AMAL)	- - - - - - Less than 0.5 m tall in 18 years - - - - - - -									
Maple (ACGL)	- - - - - - Less than 0.5 m tall in 18 years - - - - - - -									

[1] Equation form: $Y = \frac{a}{1+be^{-ct}} = \frac{gh}{1+be^{-ct}}$

(h = habitat coefficient; g = genetic potential).

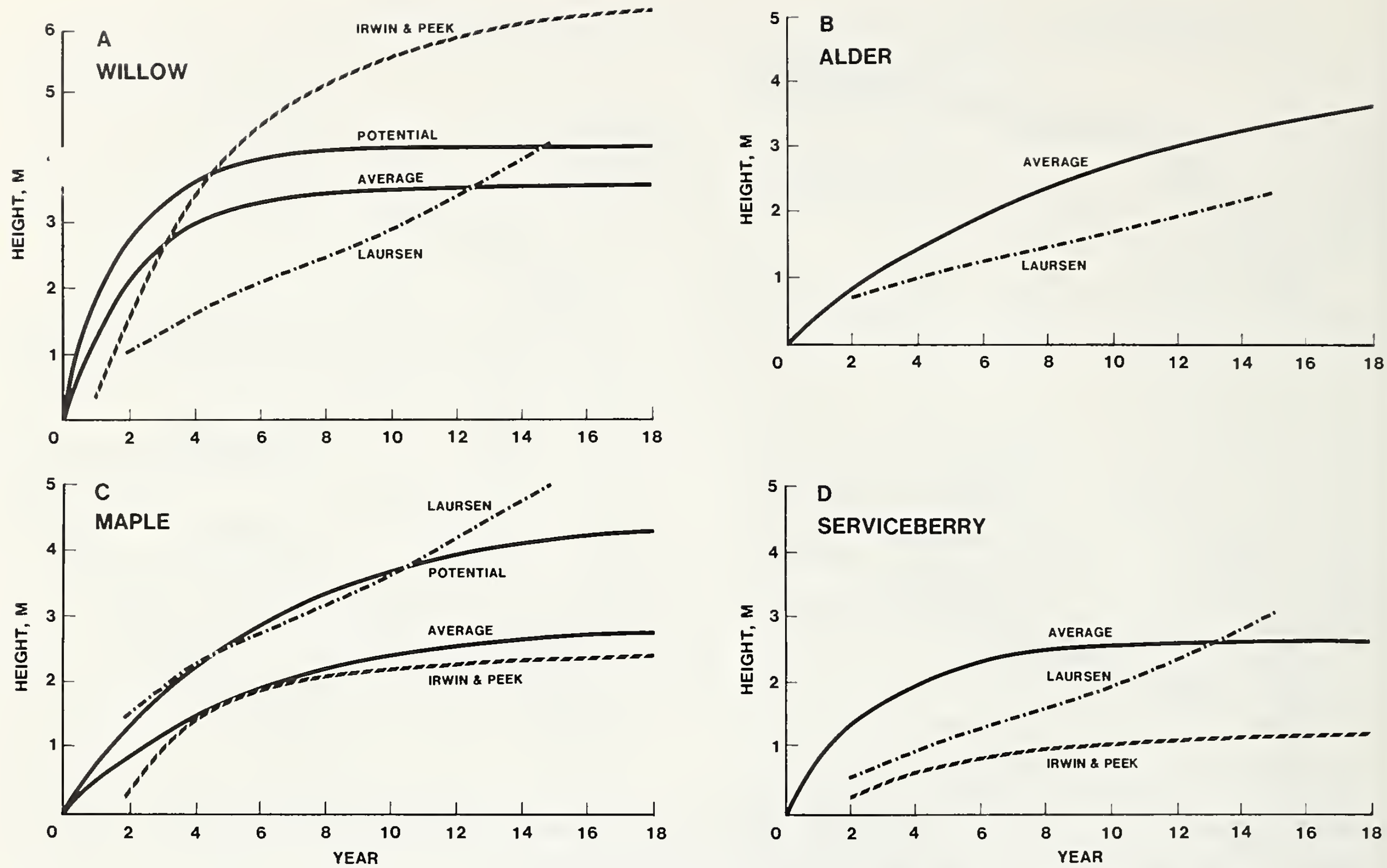

Figure 5--Comparisons of height growth equations reported here for the four tall shrub species with those reported by Laursen (1984) and Irwin and Peek (1979).

A major difference between these published height predictions and those presented here is the difference in model forms. Laursen and Irwin and Peek used lognormal linear regression models, while I used variations of an exponential model. Laursen's and Irwin and Peek's data also included resprout and seedling growth, which have different development rates. Clearcut and burn or wildfire treatment severity and stand history variation for Laursen's and Irwin and Peek's data are much greater than for Stickney's sites. This added variation, at least in Laursen's data, may explain why the r^2 values for his equations are from 0.18 to 0.35, as compared to 0.72 to 0.93 (tables 4 and 5) for my equations. Variation associated with data for stands to 70 years of age is also included in Laursen's work.

Low Shrubs and Herb Development

A number of studies have shown that understory herbage production increases dramatically after removing the lodgepole pine overstory (Basile and Jensen 1971; Trappe and Harris 1958). Other studies (Austin and Urness 1982; Conway 1982; Dodd and others 1972) demonstrate that herbaceous biomass production is inversely related to the amount of lodgepole pine overstory. The relationship in British Columbia (Dodd and others 1972) was strong enough that herbage production could be estimated by measuring tree canopy cover on aerial photographs.

Although the amount of light that reaches the forest floor is inversely related to the amount of overstory canopy, the primary effect of the overstory on understory biomass is due to reduced moisture rather than to light (Tisdale and McLean 1957). Donner and Running (1986) determined that water stress in lodgepole pine was directly related to the residual basal area and thus overstory canopy coverage. They sampled stands thinned to several densities.

The range of maximum understory productivities following clearcutting is not great in Montana lodgepole stands, ranging from 800 to 1,000 pounds annually per acre, and occurring about 11 years after cutting (Basile and Jensen 1971). Basile (1975) showed that moisture and available potassium in the soil significantly influenced productivity. Some personal observations indicate that severe scarification can delay the time to peak productivity. In wide-spaced thinnings (18 by 18 feet) in 10- to 15-year old stands, maximum productivity may extend to 30 years after clearcutting (Conway 1982). These maximum levels of productivity may be obtained in older stands that are thinned, if the residual overstory canopy coverages are low.

Given the present state of knowledge, the work of Basile and Jensen (1971) provides the best basis for predicting understory biomass development following clearcutting of lodgepole stands in Montana. For this procedure, a curve (fig. 6) was derived using their data, with time since

cutting as the only independent variable. Predictions of biomass can be made directly from this figure.

Figure 6--Biomass production of forbs and grasses over time following clearcutting and site preparation in lodgepole stands in Montana (from Basile and Jensen 1971).

Where partial cutting or thinning treatments are imposed, biomass predictions can be made using the equation:

$$\text{Biomass } \frac{(\text{pound})}{\text{acre}} = 0.89(874 - 7.76X) \qquad (11)$$

where X is the tree canopy cover in percent.

This equation was derived from Conway (1982) by using his data from the Gallatin and Lewis and Clark National Forests. An r^2 of 0.66 indicates a relatively strong relationship between dependent and independent variables. Figure 7 illustrates the equation fit to the data points.

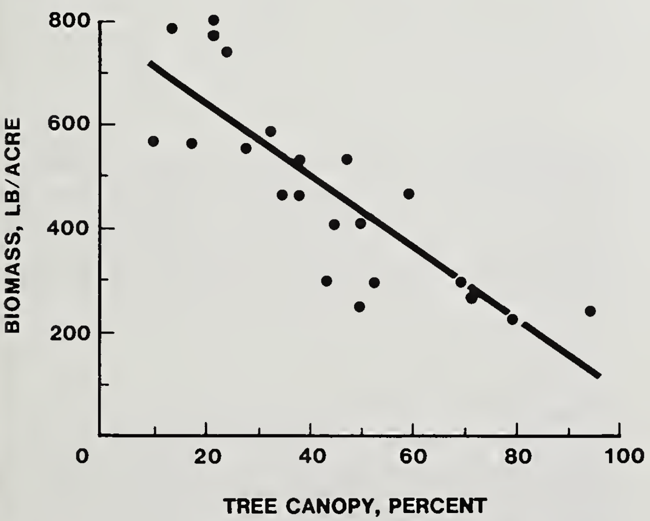

Figure 7--The relationship between percent tree canopy cover and understory biomass production (adapted from Conway 1982).

AN EXAMPLE OF APPLYING THE PREDICTION PROCEDURE

This section summarizes the data needed to use the prediction procedure, and illustrates the predicted understory growth consequences of three treatment scenarios.

Data Needed

Table 6 summarizes the data needed to use the prediction procedure, and indicates potential sources for the data. Table 6 applies to the 28 species discussed in this paper and to the habitat types included in tables 2 and 3. Values for other species and habitat types would have to be generated from the literature and expert judgment.

Comparison of Three Scenarios

Expected community structure, as influenced by treatment and survival strategy, will be illustrated by using a specific stand with three treatment scenarios: (1) a clearcut with burning for site preparation, (2) a thinning that removes 50 percent of the basal area, and (3) a clearcut with bulldozer scarification for seedbed preparation.

Site Description--The site used for this example is an 88-year-old lodgepole pine stand in the Deerlodge National Forest near Georgetown Lake, MT. Elevation is 6,700 feet on a 20 percent northwest-facing aspect. Before treatment the stand was stocked with 6,000+ live stems per acre that averaged 2.5 inches in diameter and 40 feet in height. Habitat type is PSME/LIBO-CARU; mean annual precipitation is about 18 inches.

Pretreatment inventory of low shrub and herb coverage and tall shrub spacing and cover are shown in table 7. Densities for Sitka alder (90 per acre) and Scouler willow (16 per acre) are average values for the stand. Plants are actually clumped with much higher densities (up to 1,500 per acre) in some parts of the stand. To illustrate the procedure I assume the plants are randomly but evenly distributed at the average spacing (fig. 8) to describe community development for the three treatment scenarios. Figure 8 shows an aerial view of the spacing and the plot area to be shown in the following figures. The observer is located 50 feet from the stand edge and 10 feet above the ground surface.

Clearcut With Broadcast Burn--For this example, I assume that the burn (following cutting) consumed all the aboveground vegetation and consumed the duff so that about 50 percent of the mineral soil is exposed. The depth of lethal heat penetration is expected to be about 1 cm. For purposes of simplification I will only project development for the species shown in table 7. In reality many other species may be of interest even though the species in table 7 will provide the major impact. Tree regeneration is important from the standpoint of the future stand and its impact on the understory species, but I have not included tree regeneration in these examples.

Table 6--Summary of data and sources needed for the procedure to predict understory vegetation response to treatment

Data needed	Source
	Plant Data
Species composition	Sampling of pretreatment stand to identify important species
Tall shrub density	Sampling of pretreatment stand to determine number per acre
Tall shrub clumpiness	Sampling of pretreatment stand to determine average distance between individuals
Species survival strategy	Table 1 for 28 species
Seedling establishment probability (tall shrubs)	Table 2 for Scouler willow and Sitka alder by habitat type
Potential height (tall shrubs)	Table 4 for resprouts; table 5 for seedlings. Values are based on curve fitting
Site correction (tall shrub height)	Table 3 for Scouler willow, Sitka alder, Rocky Mountain maple, and western serviceberry. Values based on expert judgment
Overstory canopy (percent)	Values based on prescription targets and later values from growth models (Prognosis or LPPIM)
	Treatment Data
Surface disturbance (areal extent)	Supplied by the user; based on expected treatment disturbance (percent of surface)
Depth of disturbance	Supplied by user; based on expected treatment disturbance (depth for area disturbed to establish mechanical or lethal heat penetration)
Mineral soil exposed (percent)	Supplied by user; based on treatment target for prescription
	Site Data
Habitat type	User-supplied for specific site

Table 7--Primary plant species spacings and ground coverage for an 88-year-old lodgepole pine stand (Echo Lake) in the Deerlodge National Forest

Species	Spacing	Density	Coverage
	Feet	No./acre	Percent
	Tall Shrubs		
Scouler willow	52	16	1
Sitka alder	22	90	10
	Low Shrubs and Herbs		
Rusty menziesia	--	--	T
Shiny-leaf spirea	--	--	T
Globe huckleberry	--	--	2
Whortleberry	--	--	13
Broadleaf arnica	--	--	40
Showy aster	--	--	T
Pinegrass	--	--	T
Fireweed	--	--	T
Rattlesnake-plantain	--	--	T
Twinflower	--	--	3
Sidebells pyrola	--	--	T

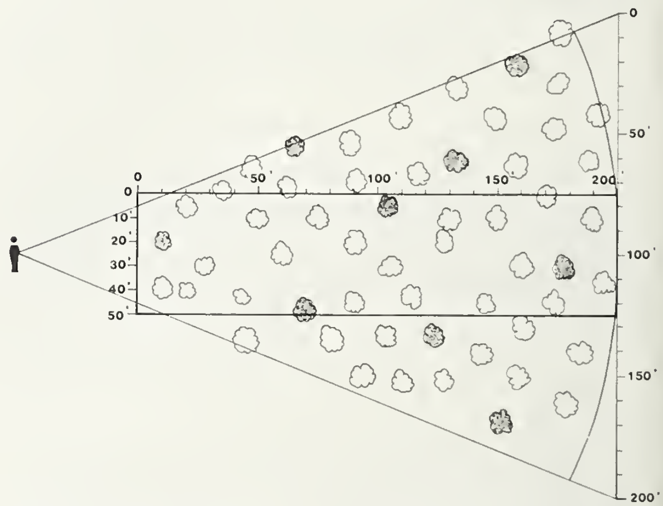

Figure 8--Aerial view of survivor shrub spacing in the example stand used in the three treatment scenarios. The location of the observer and the field of view used in the developing community diagrams is shown. The open diagrams represent Sitka alder and the shaded ones represent Scouler willow.

Scouler willow and Sitka alder have root crown structures (table 1). These are fairly massive structures and are expected to resprout. Dwarf huckleberry and shiny-leaf spirea have rhizomes located from 1.5 to 5 cm or more in depth. These rhizomes will also survive this treatment and resprout. Most forbs and grasses listed in table 6 will also survive and be present in the

initial posttreatment community. Twinflower and sidebells pyrola coverage will be reduced significantly by burning, because the points of sprouting will be consumed, at least on the 50 percent of the area where mineral soil is exposed. Figure 8 shows the expected density of the surviving tall shrubs. Relative spacing is the same as in the pretreatment stand.

Figure 9A shows how the shrubs are expected to look on this site 2 years following treatment. The spacing reflects a 5 percent mortality for Scouler willow and Sitka alder. This level of mortality is assumed, based on Stickney (1980, 1985, 1986a) and Lyon (1971), where very little mortality was noted after burning. Expected seedling establishment for Scouler willow (79 spots stocked per acre) is shown based on the 50 percent mineral soil exposed and habitat correction (table 2) put into equation 1 for Scouler willow seedling establishment. Equations 8 and 10 were used to project height development of resprouts and seedlings. Values for the potential height coefficients for no canopy in tables 4 and 5 were plugged into the equations. The habitat type correction for height growth is obtained from table 3. Crown shape is stylized for these species with width from height-width ratios developed from Stickney's (1986b) measurements.

Using the growth equations for the shrubs, Scouler willow and Sitka alder resprouts are shown to grow rapidly. Growth rates will result in these shrubs appearing as in figure 9B in year 6. Scouler willow and Sitka alder resprouts will be up to 12 feet tall. New Scouler willow seedlings are shown at 2 feet tall and at 23-foot spacings. New seedlings of Sitka alder (225 spots stocked per acre) will become established about year 8 in the vicinity of the parent plants. Equations 5 and 6 are used to calculate N and input into equation 2 to calculate the number of potential spots stocked. By year 20 (fig. 9C) the shrubs are approaching their maximum heights for the site, with Scouler willow at 13 feet and Sitka alder at 15 feet. Scouler willow and Sitka alder seedlings have grown to equal heights of resprouts. Figure 9D shows the appearance if no seedlings had become established. Tree regeneration, if stocking was adequate, would be nearly 15 feet tall and influencing development of the shrubs. It will be important to model the effects of varying levels of tree regeneration in the future.

Biomass of low shrubs and herbs is obtained from figure 6. Ground layer vegetation (which is primarily broadleaf arnica, pinegrass, and twinflower) will produce about 500 pounds per acre annually at 5 years, will peak at 800 pounds per acre at 10 years, and will decrease to pretreatment levels of 300 pounds per acre at 20 years.

Thinning--Removing 50 percent of the basal area of this stand, by thinning from below, will result in a stand with 1,000 trees per acre and a basal area of 110 feet per acre, and a 50 percent canopy. Thinning will cause much less surface disturbance than the clearcut treatment. Most of the aboveground parts of the understory will be cut off or damaged during treatment. Because the underground parts of the plants are essentially undisturbed, almost all plants are assumed to survive the treatment. Sprouting will be stimulated, but the response will not be as rapid as in the clearcut example. Shrub density in year 2 will appear as in figure 10A. Growth response, as calculated for the clearcut and burn example but using the coefficients in table 4 for the 80 percent canopy, will be slower due to the presence of the residual tree canopy that uses the moisture and provides shade. This will result in an appearance by year 6, as shown in figure 10B. Shrubs are much shorter than following clearcutting (Scouler willow 6 feet and Sitka alder 4.5 feet).

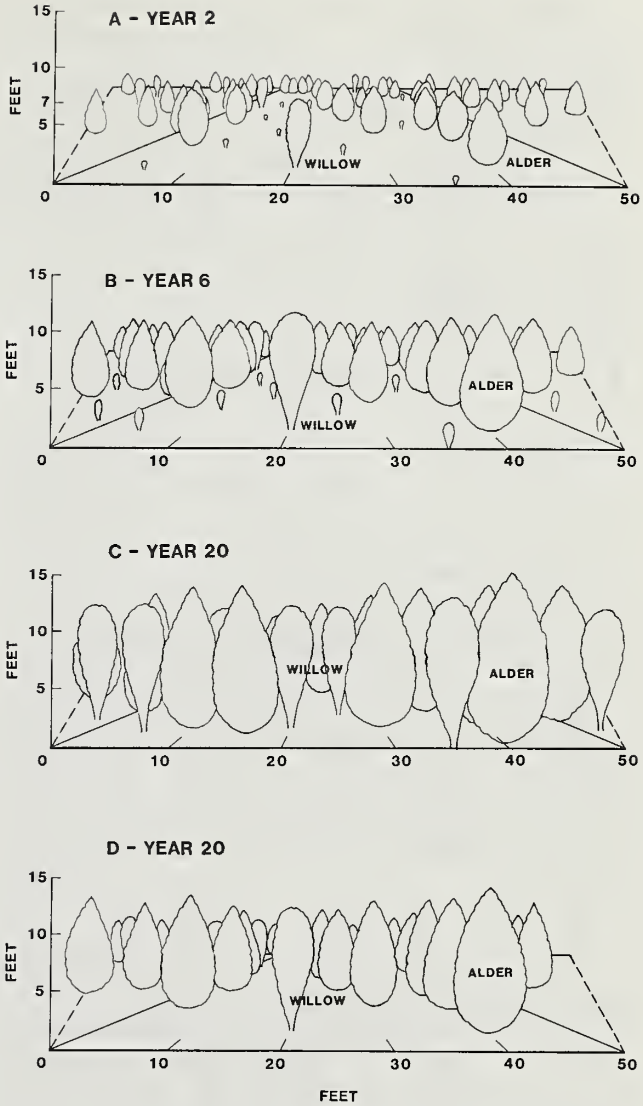

Figure 9--Heights and density of Scouler willow and Sitka alder as they are expected to appear following clearcutting in year 2 (A), year 6 (B), and year 20 (C). Seedlings of Scouler willow and Sitka alder are shown as they are expected to be in A, B, and C. Year 20 is shown without seedlings in D.

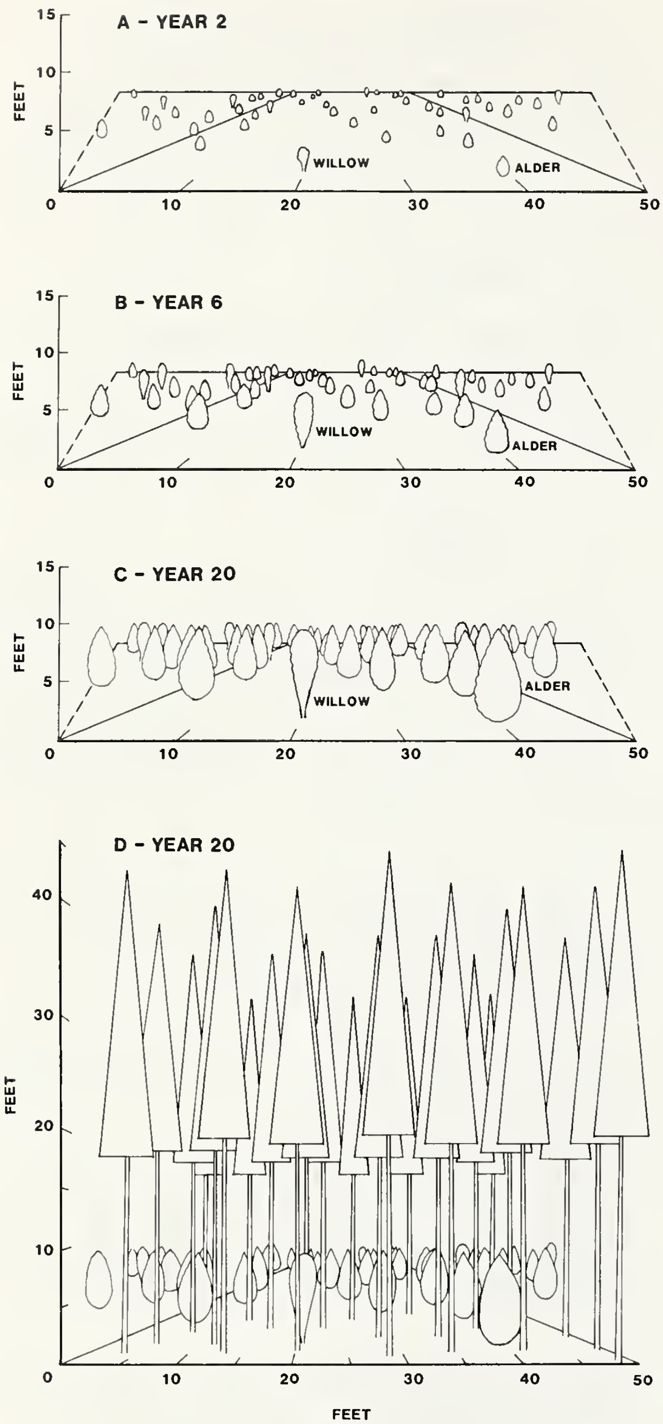

Figure 10--Heights and density of Scouler willow and Sitka alder as they are expected to appear following removal of 50 percent of the basal area in a thinning--year 2 (A), year 6 (B), and year 20 (C). Year 20, as it would appear with leave trees, is shown in D.

By year 20 (figure 10C) maximum shrub height is about 10 feet. As the tree crowns continue to develop, Sitka alder and Scouler willow will decline and eventually die. Death of shrubs would occur sooner in the untreated stands. Because mineral soil was not exposed during the treatment, seedlings of Scouler willow or Sitka alder will not become established. Figure 10D shows how the community might be expected to look at year 20 with the residual lodgepole trees included.

Biomass with this overstory canopy is calculated using equation 11. The ground layer vegetation in this scenario will respond somewhat to the opening, with maximum productivity of 400 to 500 pounds per acre (fig. 7) at 5 to 10 years after treatment. When the canopy closes, productivity will decline to pretreatment levels of around 200 pounds per acre.

Clearcut With Severe Mechanical Scarification--This example is representative of treatment with a bulldozer where mineral soil is disturbed to a depth of 2 inches or more on 100 percent of the area. Although this seems extreme, I have seen such examples. Matching this treatment with the species attributes in table 1, I would expect the root crown shrubs (Scouler willow and Sitka alder) to be uprooted and thus largely lost from the site. Because dwarf huckleberry and shinyleaf spirea are rhizomatous species, they would survive even though some rhizomes would be killed. Of the forbs and grasses in table 7, twinflower and sidebells pyrola would be lost and the other species would survive, but the amounts would be reduced.

Because so much mineral soil is exposed, more than adequate stocking of lodgepole pine would occur. The likelihood of Scouler willow seedlings and other invaders becoming established is good. If I assume 100 percent mineral soil exposure and good conditions for Scouler willow seedling establishment, then 159 potential spots would have Scouler willow seedlings. In contrast to the other two treatments, we would have no tall shrubs surviving the severe scarification. The community structure would be much different at years 2 and 5 from that shown in figures 9 and 10. By year 20 the seedlings would have grown to a height of 13 feet. The appearance of the stand would be somewhat similar to figure 9C, except no Sitka alder would be present.

Biomass at 20 years may not exceed the level present before treatment. In some cases (depending on seed sources), colonizers such as pinegrass and fireweed may make a significant impact. Shrubs and herbaceous vegetation would not be competing with the tree regeneration, but the stocking may be great enough that thinning would be required. It may be that the lack of understory vegetation would not meet other resource needs. Also, the high level of mineral soil exposure may result in unacceptable site conditions.

Any number of other treatment possibilities could be examined using this procedure. With an adequate display of community structure (such as in figs. 9 and 10), the consequences of alternatives could be at least initially judged to determine how well they fit management objectives.

IMPLICATIONS

Looking at the understory vegetation and its development relative to treatment and pretreatment conditions reveals a number of implications for the lodgepole pine stands in Montana. It is apparent from Lyon and Stickney (1976) and Stickney (1986a, 1986b) that the original pretreatment species composition is very important. Only for a few species, such as Scouler willow and fireweed, can a species not present at the beginning make much of an impact on the plant community after treatment.

The plant survival strategies and treatment combinations discussed here, and shown by examples, are quite important in determining what species, and what amounts, will be present following treatment. It is obvious from the examples that some species can be lost, or at least reduced in abundance, while other species may be increased or added as a result of specific treatments. Whether these changes are desirable or not depends on the management objectives and expectations for the posttreatment stand.

From a wildlife manager's point of view, cover and forage changes resulting from harvesting are important. Hiding cover is maximized at heights from 1.0 to 1.5 m (3.5 to 5.0 feet) (Lyon and Jensen 1980). Based on the height growth curves derived here (fig. 4), resprouts of western serviceberry, Rocky Mountain maple, Scouler willow, and Sitka alder will all provide hiding cover by year 4 in clearcuts. Scouler willow and Sitka alder are capable of providing hiding cover in the first year. Where an overstory canopy exists and resprouts are shaded, it may take from 4 to 10 years to get hiding cover. In the absence of resprouts, seedlings of Scouler willow and Sitka alder can take from 8 to 14 years to provide hiding cover.

Potential forage production for wildlife or domestic livestock can often increase dramatically following a clearcutting (fig. 6) and is also closely tied to the amount of overstory canopy (fig. 7).

The amount of hiding cover and the rate at which it develops are quite different for the three scenarios presented. In the clearcut and burn scenario the shrubs are tall enough to provide some hiding cover by year 2; by year 6 they have filled out enough to provide considerable hiding cover (fig. 9B). By year 20 the fully developed 420 Scouler willow and Sitka alder per acre (includes resprouts and seedlings) provide 100 percent hiding cover (fig. 9C). In the thinning scenario, minimal hiding cover is produced by year 6; by year 20 the 106 Scouler willow and Sitka alder per acre (resprouts) provide much less hiding cover than the clearcut scenario (fig. 10). In the third scenario, clearcut with severe mechanical scarification, all the original plants are killed so the only cover provided by shrubs is from Scouler willow seedlings. The 159 Scouler willow seedlings per acre will not be tall enough by year 6 to provide hiding cover, but by year 20 they will provide about 90 percent. Seedlings of lodgepole may provide considerable additional hiding cover in both clearcutting examples.

I have not explored the interaction of shrub development with lodgepole regeneration here, but this competition is important. In situations where the density of shrubs is considerable, possibly the first example, they may reduce lodgepole regeneration. Depending on silvicultural objectives and expected stocking, this may be good or bad. Application of these principles through a prediction methodology should help in manipulating pretreatment vegetation to fit management objectives, whether they emphasize wildlife, visual, site protection, silvicultural, or some combination of resource concerns.

If it is important to maintain some of these tall shrubs in the community, or increase them, this procedure and some of my observations are important. Given the fact that in recent history fire suppression has increased the interval between fires in lodgepole stands, they have avoided significant disturbances longer. Because these stands are becoming more closed, intolerant and semitolerant species such as Scouler willow, Sitka alder, and western serviceberry are dying out. For example, on the control plot of the example site, a number of Scouler willow root crowns are dead. If, as suspected, these plants originated from several fire cycles, continued losses may be hard to replace. They are unlikely to be replaced following one disturbance or treatment unless they are physically planted on the site.

CONCLUSIONS

1. Vegetation response to stand treatment alternatives can be assessed effectively by considering species attributes and growth rates in concert with expected levels of disturbance.

2. This prediction procedure is useful for situations where long-term data on treatment responses are not available.

3. Changes in vegetation structure used to describe developing plant communities can be valuable for assessing the consequences for wildlife, timber production, visual concerns, and grazing potential.

4. The equations presented describe height growth development of Scouler willow, Sitka alder, Rocky Mountain maple, and western serviceberry resprouts quite well. They can be used to make reasonable predictions of resprout height growth for these shrubs.

5. The sigmoid-shaped function presented describes height growth development of Scouler willow and Sitka alder seedlings quite well. It can be used to make reasonable predictions of seedling height growth for these shrubs.

6. Observations indicate that many plants of the tall shrub species are likely to be lost from old, small-stem lodgepole pine stands.

7. When tall shrubs are lost from these lodgepole pine stands, they may not be readily replaced by seed with future treatments. It may take more than one disturbance cycle to replace lost numbers.

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APPENDIX A

SCIENTIFIC NAMES OF PLANTS IN TEXT AND TABLES

Common name[1]	Scientific name
Tall Shrubs	
Black elderberry	*Sambucus racemosa*
Rocky Mountain maple	*Acer glabrum*
Rusty menziesia	*Menziesia ferruginea*
Scouler willow	*Salix scouleriana*
Sitka alder	*Alnus sinuata*
Western serviceberry	*Amelanchier alnifolia*
Low Shrubs and Herbs	
Baldhip rose	*Rosa gymnocarpa*
Beargrass	*Xerophyllum tenax*
Broadleaf arnica	*Arnica latifolia*
Common juniper	*Juniperus communis*
Dwarf huckleberry	*Vaccinium caespitosum*
Elk sedge	*Carex geyeri*
Fireweed	*Epilobium angustifolium*
Glacier-lily	*Erythronium grandiflorum*
Globe huckleberry	*Vaccinium globulare*
Kinnikinnik	*Arctostaphylos uva-ursi*
Pinegrass	*Calamagrostis rubescens*
Prickly rose	*Rosa acicularis*
Rattlesnake-plantain	*Goodyera oblongifolia*
Russet buffaloberry	*Shepherdia canadensis*
Shiny-leaf spirea	*Spiraea betulifolia*
Showy aster	*Aster conspicuus*
Sidebells pyrola	*Pyrola secunda*
Snowberry	*Symphoricarpos albus*
Strawberry	*Fragaria virginiana*
Twinflower	*Linnaea borealis*
Utah honeysuckle	*Lonicera utahensis*
Wheeler bluegrass	*Poa nervosa*
Whortleberry	*Vaccinium scoparium*

[1]Names are from Hitchcock and Cronquist (1973).

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RESIDUES, BENEFICIAL MICROBES, DISEASES, AND SOIL MANAGEMENT IN COOL, EAST SLOPE, ROCKY MOUNTAIN LODGEPOLE PINE ECOSYSTEMS

A. E. Harvey, M. F. Jurgensen, and M. J. Larsen

ABSTRACT: Manipulation of forest residues has the potential to cause substantial changes in forest floor depth and composition. Such changes alter microbial communities and the accumulation, availability, or loss of soil nutrients. Forest floor changes can also alter risk factors for certain diseases and activities of ectomycorrhizal and nitrogen-fixing microbes. Alterations of soil composition or structure are likely to have both long- and short-term impacts. Natural regulation of forest floor thickness, composition, and associated processes, primarily through wildfire, generally causes extreme fluctuations in microbial activities, nutrient storage, and nutrient release. The latter is usually poorly coordinated with forest stand needs. Silvicultural systems, stand prescriptions, and regeneration methods should be directed to improve long-term nutrient storage, and to coordinate nutrient release with stand needs. Harvesting should incorporate disease sanitation, where appropriate, and limit residual stand damage.

INTRODUCTION

Development of a knowledge base for dealing with the cold, infertile ecosystems typical of the Rocky Mountain crest, particularly eastern slopes, has generally lagged behind that for warm, more productive systems. However, sufficient information is available for preliminary interpretations of advantages and disadvantages of dealing with soils and microbes in east-side Rocky Mountain sites likely to be forested with dense stands of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Before discussing soil-soil microbe interactions and growth of this tree species, it is desirable to examine specialized adaptations of the genus *Pinus*, and to a lesser extent other conifers, that enable productive growth in low- fertility ecosystems. It is also helpful to review some of the more influential environmental characteristics of the Rocky Mountains.

Members of the genus *Pinus*, particularly lodgepole pine and closely related species, are well adapted for, and highly successful in, low-productivity, infertile ecosystems (Miller and others 1979). Three particularly important characteristics of conifers in general, and pines in particular, make them well suited to infertile, moisture-limited environments: (1) pines are strongly mycorrhizal, a characteristic that enables them to acquire moisture, nitrogen (N), and phosphorus when quantities are too low to be available to many other plants (Harley 1969); (2) in the absence of intense competition (Worrall and others 1985), pines normally have a relatively high root/shoot ratio throughout their lives, thus maximizing soil exploration and mycorrhization to enhance nutrient and moisture acquisition (Chapin 1980; Miller and others 1979); (3) pines are adept at storing nutrients within tissues, then remobilizing and transporting them to growing tissues in times of general shortage or during temporary interruptions of supply (Chapin 1980). These properties enable pines to tolerate, even thrive, in low fertility, periodically disturbed ecosystems with limited moisture typical of east-slope Rocky Mountain sites. Periodic stress caused by wide climatic fluctuations, both long- and short-term, is also typical of these environments, as are periodic insect and disease problems (Fellin 1980; Saestedt and Crossley 1984).

Lodgepole pine is frequently found on impoverished soils such as cold-wet or cold-dry, young soils (Cochran 1985). Soils on the east slopes of the Rockies are skeletal (young) soils, low in organic matter and nutrients (particularly nitrogen and phosphorus), and are moisture limited. Various soils of low water permeability and high density are also common (Cochran 1985).

Considerable genetic variation exists within the population of lodgepole pine occupying east-slope Rocky Mountain ecosystems. Differentiation within this widespread population occurs across relatively minor environmental gradients, particularly for cold hardiness, periodicity of shoot elongation, and disease resistance (Hoff 1985; Rehfeldt 1985). There is a strong elevational factor in this

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variation (Rehfeldt 1985). Thus, in a highly diverse climatic, physiographic, and geological environment, tree adaptation to local conditions is important for good performance and for moderating pest-related problems.

Lodgepole pine is usually considered a fire-maintained seral species, although its characteristics vary considerably. It is an aggressive species, highly suited to pioneering environments. Cone serotiny provides an excellent means of storing and protecting genetic materials in a fire-dominated ecosystem. However, periodic stand replacement by fires is common, serotiny is variable, and fuel accumulations are sometimes high (Lotan and others 1985). Therefore, genetic materials are likely often at risk. At least local, and perhaps extensive, maladaptation of lodgepole populations in some environments is probably common though perhaps of short duration.

For example, as described by Romme and Knight (1981), midslope fires are more common than low- or high-elevation fires. If a hot, seed-destroying, midslope fire occurs, reforestation is likely to result from high- or low-elevation seed not well adapted to the midslope site. Thus, fire history may control local adaptation and even localized maladaptation may lead to poor performance and pest damage.

East-slope Rocky Mountain lodgepole pine represents a genetically fine-tuned, aggressive species operating on slim resources in a disturbance-prone, harsh, highly variable environment where constant physiological and genetic adjustments are required. In short, it is a highly dynamic system where trees are likely to be responsive to plant-microbe interactions, either positively or negatively. In discussing these interactions, we will emphasize microbial processes involved in the nitrogen economy of the soil (primarily fixation and mineralization, see table 1), uptake of nutrients (especially nitrogen) by pine root systems through the formation and activity of ectomycorrhizal fungi, and activities of specific pathogens (primarily endemic root rots) as exemplified by species of *Armillaria*. Other pathogens in lodgepole pine ecosystems, some more important than root rots, have been discussed elsewhere (Krebill 1975; van der Kamp and Hawksworth 1985).

NITROGEN DYNAMICS AND SOIL ORGANIC MATTER

Most site N reserves are incorporated into the molecular structure of soil organic matter (OM). The remainder is incorporated into living or dead plant bodies. Aspects of how N is brought into and moves within soil, root, and aboveground components of an ecosystem are useful in determining how best to deal with a nutrient usually limiting to tree growth. Table 1 defines terminology required to examine N dynamics.

Active N conversion processes are common to all ecosystems, but rates, quantities, and distributions are variable. Management options can be limited by any of these three factors. East-slope lodgepole ecosystems are most likely to be constrained by low amounts of total N accumulation (either from fixation or

Table 1--Definition of terms used to describe aspects of the nitrogen economy of forest soils

Term	Definition
Fixation[1]	Conversion of atmospheric N to soil N.
Nonsymbiotic	By organisms (bacteria and algae) living free in soil and other environments.
Symbiotic	By organisms (bacteria) within root nodules of living plants.
Available N	That portion of soil N in a form usable by plants.
Immobilized N	That portion of soil N tied up in organic compounds of living or dead organisms and not available for uptake by vegetation.
Mineralization[1]	Process of converting immobilized N to available N through microbial decay (bacteria and fungi).
Ammonia	NH_3, a preferred form of available N for lodgepole pine.
Nitrate	NO_3, a form of available N subject to leaching loss.
Nitrification	Process of converting NH_4 to NO_3 by nitrifying organisms (bacteria).
Total N[1]	Total amounts of organic and inorganic N, all forms (N storage).

[1]Potentially most limiting to N economy of lodgepole ecosystem.

atmospheric pollution) and slow rates of conversion (mineralization) into a form suitable for uptake by pine roots (Yavitt 1984; Yavitt and Fahey 1986). Both are temperature and moisture limited--major considerations on Rocky Mountain sites.

Table 2 shows the distribution of total nitrogen in two contrasting lodgepole stands in Wyoming; one is a typical small-stem, doghair stand, the other an open-grown stand. These data show that soil OM, including decayed woody debris, stores well over half the total N on these sites. Most of the rest is contained in small branches, twigs, foliage, or fine roots. Stem components have relatively small amounts of N, although the doghair stand has more N in bolewood than the open-grown stand (Yavitt 1984). Thus, harvesting or site preparation methods that destroy, displace, or remove nonbolewood components are likely to impose significant losses on N reserves.

Minor losses of nitrogen are probably not a great problem on many sites with good sources of N input, either biological (fixation) or via air pollutants. However, most east-side lodgepole pine sites have neither. Table 3 provides some estimates of major inputs and losses of N to an east-side forest soil, again based on a study in a Wyoming lodgepole stand. These data emphasize that rates of external input are low and that most of the N available for tree growth comes from internal cycling processes (Yavitt 1984). Any substantial losses of N reserves will be replaced slowly and are likely to cause productivity loss (Flinn and others 1980; Weber and others 1984). Because most of the site N reserves are contained in soil OM layers, depth variations from site to site or OM losses are likely to be reflected in growth rates of the trees (Graham and others in press; Weber and others 1984).

Examining an annual root zone N budget is instructive for analyzing N transfers within an ecosystem. Table 4 shows that most of the N in the root zone is contained in soil organic materials or in tree roots, and that movement of nitrogen among soil components and plant

Table 2--Total nitrogen distribution in contrasting 80- to 100-year-old _Pinus contorta_ ecosystems of Wyoming, calculated from Yavitt (1984)

	Doghair stand		Open stand	
	- - - - Percent - - - -			
Trees				
Foliage	[1]10		[1]7	
Branch and twig	[1]6		[1]7	
Bole	[1]8		[1]6	
Root crown	1		1	
Lateral roots	5		1	
Fine roots	11		7	
Total	41		29	
Debris				
O_1 horizon	[1]17		[1]14	
O_2 horizon	[1]37		[1]40	
Total	54		54	
Dead fall	5		0	
Dead wood	0		[1,2]17	
Total	5	[3]83	17	[3]91
Total for all soil OM to 100-cm depth	570g/m^2			650 g/m^2
Ecosystem total	618g/m^2			735 g/m^2

[1]Sources of N highly vulnerable to burning or mechanized removal.
[2]Where a previous old-growth stand was terminated by wildfire and substantial volumes of bole wood remained, N storage in the decayed wood component can exceed that stored in the other debris components by two to three times (Fahey 1983).
[3]Total percentage of N that is vulnerable to burning or mechanized removal.

Table 3--Some major soil nitrogen gains and losses from a typical, 80-year-old Wyoming lodgepole pine stand, calculated from Yavitt (1984)

Source	Percentage annual N budget
Gains	
Rain	5
Snow	2
Throughfall	8
Nonsymbiotic fixation	<1
Symbiotic fixation	3
Litter fall	17
Mineralization release from soil OM	25
Losses	
Immobilization in soil OM	14
Vegetation uptake	25
Leached to or below subsoil	<1

uptake are slow (Yavitt 1984). In particular, mineralization activities are extremely slow. Although this is a potential advantage from the standpoint of nitrate loss below the root zone (Vitousek and others 1982), it also shows that the temperature and moisture limitations of these soils inhibit the decay process and make it difficult to get N released from soil OM. Not only is it difficult to get N on these sites, it is also a problem to get the N released in a form suitable for uptake and use by the trees (Fahey 1983; Yavitt and Fahey 1986; Yavitt 1984).

Although the process of nonsymbiotic nitrogen fixation contributes little to N input in an 80-year-old Wyoming lodgepole pine stand (Yavitt 1984; table 3), this process is active in western Montana forest ecosystems (Jurgensen and others 1979; Larsen and others 1980). Also, at least under relatively warm, moist, midsummer conditions, nonsymbiotic N-fixation rates at a high-altitude, western Wyoming site can be substantial (Jurgensen and others 1982). Rates of fixation and daily accumulation can be at least as high as those in western Montana (table 5). However, warm, moist conditions are infrequent in east-side forests, so annual accumulations from this source are likely small.

Because N-fixing organisms can be effective in east-side lodgepole pine soils under appropriate conditions, management actions that increase soil moisture or temperature should enhance nonsymbiotic nitrogen fixation (and mineralization). Because decayed and decaying wood can be particularly active sites of nonsymbiotic N fixation (Larsen and others 1980), modest quantities of postharvest woody residues left on site should further enhance nitrogen input, as would encouraging symbiotic N-fixers as components of the understory vegetation (Jurgensen and others 1979, 1982; Yavitt 1984).

Rates of wood decay reported for Montana and Wyoming sites (Fahey 1983; Harvey and others 1981) indicate that substantial decay should occur within 60 to 100 years and that decayed wood in contact with the soil can become an important site for nitrogen storage (table 6) Large-diameter residues, if in contact with the soil, may decay faster than small ones that rapidly dry out because of the limited summer moisture on many east-side sites. This has been reported for a variety of forest ecosystems in Washington (Erickson and others 1985). Leaving large-diameter residues is also a consideration for encouraging ectomycorrhizal activities in Northern Rocky Mountain forest soils (Harvey and others 1978, 1979, 1986).

DISTRIBUTION AND ACTIVITY OF MYCORRHIZAE

Mycorrhizal infection of root systems is considered an important adaptation of pines for normally infertile ecosystems (Harley 1969;

Table 4--Annual soil root zone nitrogen budget, in percentage of total for 1 year, from typical 80-year-old Wyoming lodgepole pine stand, calculated from Yavitt (1984)

Root zone N		N conversions		Vegetation use of N	
Roots	42				
Soil organic matter (to 100-cm depth)	40	Mineralized	5	Vegetation uptake	5
Soil solution	3	Immobilized	4		
To and below subsoil	1				
Totals	86		9		5

Table 5-- Comparative nonsymbiotic nitrogen fixation rates and amounts (among soil components) between a moderate, 250-year-old, west-slope subalpine fir stand in Montana and a cool, 160-year-old, east-slope lodgepole pine stand in Wyoming (midsummer measurements) after Jurgensen and others (1982)

Soil component	Rate/day $(gN[X10^{-9}]g^{-1})$		Amount/day (gN/ha)	
	Montana	Wyoming	Montana	Wyoming
Humus	0.3	2.1	<0.1	0.1
Decayed wood	28.1	35.9	1.2	.2
Mineral transition layer[1] (0 to 5 cm mineral)	2.1	2.7	2.9	3.8
Mineral (5 to 30 cm mineral)	[2]0.7	.8	5.1	2.3

[1]Mineral transition layer described as first 5 cm of mineral soil; mineral includes the rest of the mineral soil in core sample to a 30-cm maximum depth.
[2]Based on an assumed one-third of mineral transition layer rate.

Miller and others 1979). Formation and activity of mycorrhizal root systems on lodgepole pine seems particularly important for pioneering environments with young trees (Grossnickle and Reid 1982). Lodgepole appears typical of all Pinus spp. in that it is responsive to the presence and activity of mycorrhizal fungi (Grossnickle and Reid 1982) and in some instances it may be particularly responsive to selected species of mycorrhizal fungi (Molina and Trappe 1982).

Old decayed logs deposited on or incorporated in forest soils are an important organic constituent of east-side soils. Up to 15 percent by volume of western Montana forest soils (top 30 cm) can be made up of decayed wood (Harvey and others 1976). High concentrations of ectomycorrhizal activities in soil wood have been reported during dry seasons (Harvey and others 1978) and on dry sites (Harvey and others 1979). Thus, deposits of decayed wood derived from large residues in forest soils should enhance productivity of the site for lodgepole pine in moisture-limited areas. We currently recommend that 10 to 15 tons of 6-inch+ residues/acre (2.4 to 3.6 tons of 15 cm+ residues/ha) be left on the site after harvesting (Harvey and others 1986a,b in press).

Table 7 compares the distribution of ectomycorrhizal activities between a western Montana (west side of Continental Divide) and north western Wyoming (east side) site. These data show organic soil layers are extremely limited on the east-side site when compared to the west-side site and that, despite this limitation, ectomycorrhizal activities are also concentrated in the sparse organic layers of east-slope soils.

Because organic layers constitute a shallow horizon on the soil surface, usually less than 1.7 inches (4 cm) in Northern Rocky Mountain forests, feeder root activities are usually a surface phenomenon (Harvey and others 1986). The concentration and turnover of conifer fine roots near the soil surface, particularly in organic horizons rich in nutrients (Coutts and Philipson 1977), make significant contributions to soil OM (Vogt and others 1983). Their shallow nature also makes feeder roots subject to potential disruption by management activities that disturb the soil surface (Harvey and others 1986; Perry and others 1982). Therefore, conservation of soil OM, including old, decayed residues and stumps, appears desirable in most lodgepole pine forests. However, where such materials might serve as a potential disease inoculum source, different rules must be applied.

DISTRIBUTION, ACTIVITY, AND DAMAGE POTENTIAL OF SELECTED PATHOGENS

Although it is our intent to emphasize aspects of root disease pathology in this report because of the relationship with residue and OM management, we will also review some other aspects of pathology potentially important to east-side lodgepole pine management. This review will be brief because lodgepole pine disease relationships have been discussed in recent literature (Krebill 1975; van der Kamp and Hawksworth 1985).

The five major disease classes and their relative importance to the lodgepole pine resource are: (1) dwarf mistletoe, (2) native rusts (primarily stem rusts), (3) root and stem decays, (4) stem cankers, and (5) foliar diseases (table 8). Dwarf mistletoe is a widespread, highly destructive disease. Perhaps as many as 50 percent of the lodgepole pine stands on east-slope sites are infested (van der Kamp and Hawksworth 1985). Fortunately, management methods to reduce damage from this disease are available, although applying them is often difficult.

Table 6--Decay and nitrogen content in dead lodgepole pine bole wood and residue suspended above and lying on soil in Wyoming, after Fahey (1983)

Residue description	Weight loss	Age	Specific gravity	N. content	N gain
	Percent	Yr	(g/cm^3)	Percent	Percent
Standing dead	20	110	--	--	--
Suspended deadfall	10	80	0.41	0.065	0
Deadfall on ground (cylindrical)	60	[1]55	0.34	0.085	[2]31
Deadfall on ground (compressed)	--	--	0.24	0.20	208

[1]Assumes falldown occurred at 15 years.
[2]Increase over suspended stage.

Table 7--Comparative distribution of ectomycorrhizal activity (among soil components) between a moderate 250-year-old, west-slope stand in Montana and a cool 160-year-old, east-slope stand in Wyoming. The latter supports primarily lodgepole pine; both are classified within the subalpine fir habitat series

Soil component	Soil component volumes		Number of active short roots	
	Montana[1]	Wyoming[2]	Montana[1]	Wyoming[2]
	Percent	Percent	Percent	Percent
Litter	2^{a}_{x}[3]	2^{a}_{x}	0^{a}_{-}[4]	6^{a}_{x}
Humus	13^{a}_{y}	3^{a}_{x}	74^{b}_{x}	37^{a}_{y}
Decayed wood	14^{a}_{y}	1^{a}_{y}	19^{a}_{yz}	28^{a}_{y}
Mineral transition layer[5] (0 to 5 cm mineral)	16^{a}_{y}	16^{a}_{x}	6^{a}_{y}	28^{a}_{y}
Mineral (5 to 30 cm mineral)	55^{a}_{z}	78^{a}_{z}	1^{a}_{z}	1^{a}_{x}
All organics combined	29^{a}_{x}	6^{b}_{x}	93^{-}_{x}	71^{-}_{x}
All minerals combined	71^{a}_{y}	94^{b}_{y}	7^{-}_{x}	29^{-}_{x}

[1]Montana data derived from Harvey and others (1978).
[2]Wyoming data derived from Jurgensen and others (1982); data from both States at estimated site maximum (late spring), see Harvey and others (1978).
[3]Differing letters indicate significant differences between sites (a,b) or within site (x, y, z), based on two-sided t-test.
[4]Indicates comparison not possible or available.
[5]Mineral transition layer described as first 5 cm of mineral soil; mineral includes the rest of the mineral soil in core sample to a 30-cm maximum depth.

Table 8--Fungus-caused diseases, by class, listed in approximate descending order of risk to lodgepole pine, after Ives (1983), Krebill (1975), and van der Kamp and Hawksworth (1985)(taxonomic designations as currently accepted)

a. Stem rusts

- *Endocronartium harknessii* (J.P. Moore) Y. Hirats
- *Cronartium coleosporioides* Arth.
- *C. commandrae* Peck
- *C. comptoniae* Arth.

b. Root decays

- *Armillarea mellea* (Vahl:Fr.) Quel.
- *Inonotus circinatus* (Fr.) S.C.Teng (=*Polyporous tomentosus* var. *circinatus*)
- *Phaeolus schweinitzii* (Fr.) Pat. (=*Polyporous schweinitzii*)
- *Inonotus tomentosus* (Fr.) S.C.Teng (=*Polyporous tomentosus*)
- *Phellinus weiri* (Murr.) Gilberts.(=*Poria weirii*)
- *Verticicladiella wageneri* Kendr. (=*Ceratocystis wageneri*)
- *Heterobasidion annosum* (Fr.) Bref. (=*Fomes annosus*)
- Mixtures and others

c. Stem decays

- *Phellinus pini* (Bros.:Fr.) A. Ames(=?*Phellinus vorax*)
- *Peniophora pseudo-pini* Weres. et Gibson
- *Coniophora puteana* (Schum.:Fr.) Karst.
- *Stereum sanguinolentum* (Alb. et Schwein.:Fr.)Fr.
- *Inonotus tomentosus* (Fr.) S.C. Teng
- *Dichomitus squalens* (Karst.) Reid (=*Polyporus anceps*)
- Mixtures and others

d. Stem cankers

- *Atropellis piniphilla* (Weir) Lohman et Cash
- *A. pinicola* Zeller et Good.
- *Dasyscyphus* sp. Gray
- *Tympanis* sp. Tode
- *Diplodia* sp. Fr.
- *Valsa* sp. Fr.
- Others

e. Foliar diseases

- *Lophodermella concolor* (Dear.) Darker
- *L. montivaga* Petrak
- *Elytroderma* deformans (Weir) Darker
- *Lophodermium pinastri*(Schred.ex.Hook.)Chev.
- *Scirrhia pini* Funk et Parker (=*Dothiostroma Pini*)
- *Coleosporium asterum* (Diet.) Syd.
- Others

f. Stains

- *Amylostereum* sp. (Boid.) (=*Stercum*)
- *Ceratocystis* sp. Ell. et Halst(=*Ophiostoma*)
- *Europhium* sp. A. K. Parker
- *Leptographium* sp. Lagerb. et Melin
- *Verticicladiella* sp. S. Hughes
- Others

Native rusts (*Cronartium* spp.) are also widespread and capable of inflicting heavy damage (Krebill 1975). However, geographic, site, and habitat type factors limit the distribution of several important native rusts (Beard and others 1983; Geils and Jacobi 1984). Also, in cases where an alternate host is required, there is the additional requirement for conditions suitable to support the alternate host in proximity to susceptible forest stands (Krebill 1975). Thus, distribution of many rust diseases tends to be highly discontinuous. Those that do not require the alternate host, for example gall rust, tend to be more widespread. In general, thinning, spacing, and pruning are effective controls, except where damage (and risk) is high. Under such conditions, stocking levels should be high enough to offset mortality. Genetic resistance to native rusts has been noted (Hoff 1985) and will eventually play a significant role as an aid in controlling these diseases in high-damage, high-risk circumstances.

Potentially, the most damaging root rot pathogen is likely to be *Armillaria* (James and others 1984; Krebill 1975; Morrison 1981; van der Kamp and Hawksworth 1985). However, recent work at the Intermountain Research Station indicates that *Armillaria* distribution and damage is strongly constrained by habitat type (climate) throughout most of the Inland Northwest, including many habitats likely to support east-side lodgepole pine stands (McDonald 1985, personal communication). Table 9 shows the distribution of this important pathogen, and damage patterns, on a number of east-slope sites. These data, though limited, indicate high potential for damage due to *Armillaria* activity only in relatively productive habitat types for the area (ABLA/CLUN, ABLA/MEFE, ABLA/VAGL, PSME/PHMA, PSME/VAGL). A substantial portion of east-slope habitat types may be beyond the environmental latitude of this organism and are, therefore, not likely at risk.

Table 9--Status of Armillaria on 0.04-ha plots (all conifer species)[1] located in subalpine fir and Douglas-fir habitat series in the Northern Rocky Mountains listed in approximate order of decreasing risk to disease damage, after McDonald and others [in press]

Habitat type	Climatic characterization	Number of plots	Percentage with Armillaria	Percentage with pathogenic Armillaria
Abies lasiocarpa series[2]				
ABLA/CLUN	Cool/moderate	5	80	100
ABLA/MEFE	Cold/moderate	6	83	60
ABLA/VAGL	Cool/dry	3	100	33
ABLA/ALSI	Cold/moderate	2	100	0
ABLA/ACGL	Cool/dry	1	100	0
ABLA/CACA	Cold/wet	1	0	--
ABLA/STAM	Cold/wet	1	0	--
ABLA/VACA	Frost pockets	2	0	--
ABLA/XETE	Cold/dry	6	0	--
ABLA/VASC	Cold/dry	8	0	--
Pseudotsuga menziesii series				
PSME/PHMA	Warm/dry	6	67	75
PSME/VAGL	Cool/dry	2	100	50
PSME/VACA	Frost pockets	1	0	--
PSME/JUCO	Hot/dry	2	0	--
PSME/CARU	Hot/dry	6	0	--

[1]Lodgepole pine can be considered moderately susceptible to damage by this important disease.

[2]Habitat series designations as reported in Pfister and others (1977).

In areas of high damage potential, residue management practices may affect this disease. Armillaria uses stumps, root systems, and perhaps logging slash as a food base from which to infect living trees. Thus, a reduction of food base materials should be of some benefit, at least to heavily impacted areas. This may also be the case in moderate-hazard habitat types with visible damage. Disturbance frequently leads to increased Armillaria damage (McDonald and others, in press; McDonald 1985 personal communication). However, lodgepole pine is only moderately susceptible to this disease, and most other root rots as well (Hobbs and Partridge 1979; James and others 1984; McDonald and others, in press). Therefore, the primary damage and benefits from management would likely be in fir and spruce components of mixed stands.

Other root rot and stem decay organisms also have discontinuous distribution patterns (Bella 1985; Vyse and Navratil 1985; Whitney and others 1983). In these cases, our knowledge of distribution patterns is fragmentary and not helpful for assessing potential risk in the absence of diagnosed damage in or near a stand to be harvested. Root rots, other than Armillaria, are not likely to be affected by residue management methods. Phellinus root rot management has been attempted in the Pacific Northwest with removal of infected stumps (Theis and Russell 1984). Results do not appear cost effective, particularly for low-productivity sites. It is, however, unlikely that Phellinus will cause significant damage to lodgepole pine east of the Continental Divide. Residue removal may reduce inoculum load (spores) for stem decay organisms likely to produce fruiting bodies on logging slash. However, only 16 fungi have been reported to decompose logging slash and cause significant losses in live, standing timber (Spaulding and Hansbrough 1944), and many of these are not common in the Rocky Mountains. In most cases, spores arriving from outside harvested stands are probably sufficient to cause infection of residual trees if historical damage in the stand has been high.

As with Armillaria, the incidence of other root and stem decays, and other diseases as well, can be increased with partial cutting (Bella 1985; Johnstone 1981). In most cases, the affected diseases are those already evident in the stand before harvest. In the case of high hazard Armillaria sites (table 9), damage might not be evident before harvest. In high-hazard habitat types, it would be prudent to treat as if postharvest damage by Armillaria is likely--favor resistant species and remove any infected slash.

There are potentially important root decay scenarios with lodgepole pine that involve interactions between the respective pathogens and insect pests or fire. In one, insects (Dendroctonus spp.) simply act as a vector (carrier) for black root stain (Verticicladiella spp.). This disease has considerable potential to damage lodgepole pine in the Interior West (Bertagnole and others 1983; Hobbs and Partridge 1979; James and others

1984). Fortunately, it does not persist in dead root systems, so it can be managed with appropriate harvesting.

In another scenario, fire damage to roots provides infection courts for root and stem decay organisms in Oregon. Infection predisposes trees to insect attack (*Dendroctonus ponderosae* Hopk.), providing dispersal trees that increase insect damage and mortality, eventually leading to return of fire (Gara and others 1985). Presumably, managing such stands (fuel) to limit fire could break this cycle and, in turn, reduce root rot, decay, and insect damage.

Lastly, a significant and consistent association between infection of the root pathogen *Armillaria* and incidence of infestation of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) in lodgepole pine has also been documented in Utah. In this case it was suggested that survival of the insect during its low-population cycle may be favored by the presence of *Armillaria* root disease (Tkacz and Schmitz 1986). An association with fire-damaged roots as a predisposing factor, as noted by Gara and others (1985) was not observed. However, damage by dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) and comandra rust (*Cronartium comandrae* Pk.) were noted as possible predisposing factors.

There are also two decay-related disease scenarios where exclusion of pathogens may become an important management consideration for east-side lodgepole pine. One pertains to annosus root rot (*Heterobasidion annosum*, see table 8). This pathogen, thus far, is relatively rare in lodgepole pine stands of the western United States and Canada. However, it causes a great deal of damage in other parts of the world. The organism native to our area may not be as pathogenic as elsewhere (van der Kamp and Hawksworth 1985). If so, excluding more pathogenic strains may be critical. If imported, more damaging strains may have potential to become established and cause extensive damage.

The second pathogen is the organism responsible for *Armillaria* root rot. *Armillaria mellea* (table 8) has been generally assumed to be the damage-inciting culprit. However, there is increasing evidence that several *Armillaria* species may be involved or that there may be variation within the species that affects the distribution and damage patterns shown in table 9 (McDonald 1985, personal communication). If this turns out to be the case, local and regional exclusion or measures specific to *Armillaria* species present may be helpful for limiting this disease in the future.

Most other common diseases of lodgepole pine (table 8) are only locally important and infrequently inflict major damage. *Atropellis* canker and several foliar pathogens can cause serious damage, but the damage is usually limited to small areas. If economical, development of resistance is a viable approach for dealing with many of these relatively m[illegible]r pathogens. In some instances, thinning [illegible]n reduce infection levels (Stanek and oth[illegible] 1986; Whitney and others 1983). Table 10 summarizes disease damage potential and possible controls for east-side lodgepole pine stands. All in all, our pathological problems generally appear less limiting than insect, soil productivity, silvicultural, or economic problems. However, the presence of disease damage potential, particularly by dwarf mistletoe, root rots, or native rusts, complicates other limitations because management actions that solve one problem frequently complicate or enhance others.

THE TRADEOFF PROBLEM AND SITE-SPECIFIC MANAGEMENT

Management of east-side lodgepole pine frequently presents choices in offsetting values, particularly with respect to manipulating microbial actions. For example, residue reduction (inoculum removal) for *Armillaria* control reduces N reserves, OM, and N-fixation. Similarly, fuel management involves short-term reductions of OM. However, long-term protection against excessive losses of OM, and retaining high-N-content foliage and twigs may increase inoculum for foliar pathogens. Broadcast burns that protect N reserves may not be intense enough to control competition or provide adequate site preparation. On the other hand, too much site preparation may result in high seedling density, but reduces early root proliferation and extension.

Table 11 is provided as a reminder of some hypothesized estimates of major tradeoffs to emphasize that the manager is slave to many masters. The determination of which master is most critical to a particular site is the most difficult assessment. This becomes particularly difficult in instances where time since disturbance can completely change potential impact, for example, decay of fine fuels versus large fuels. If properly determined, conflicts can be minimized, and those that remain can be addressed with reasonable confidence in an appropriate outcome.

Table 10--Relative damage and treatments for fungus-caused diseases of lodgepole pine, after Ives (1983), Krebill (1975), van der Kamp and Hawksworth (1985), Whitney and others (1983)

Disease class	Potential control	Damage potential
Stem rusts	Selective removal Alternate host control for *Cronartium* sp. Resistance	Generally moderate, but locally high
Root decays	Clearcut Stump removal or treatment Broadcast burn? Species conversion or mix Avoid or treat high hazard sites Guard against import or movement of disease organisms? Use resistance if it becomes available? Do not use highly susceptible species on high hazard sites	Generally moderate, but locally high
Stem decays	Reduce residual stand damage	Generally low, but locally high
Stem canker	Stand opening Avoid or treat high hazard sites	Locally moderate
Foliar diseases	Use resistance if it becomes available?	Generally low, but locally and temporally moderate

Table 11--Some examples of hypothesized tradeoffs between beneficial (+) and detrimental (-) environmental effects of some selected stand treatment alternatives on lodgepole pine ecosystems

Treatment alternatives	Environmental effect			
	Fire hazard	Pest hazard	Symbiont[1] activity	Nutrient supply
Clearcut (conventional utilization)	+-[2]	+-	+-	++
Clearcut (intensive utilization)	+	++	-	+-
Thin (heavy)[3]	+-	+-	+-	+
Thin (light)[3]	+-	+-	0	+
Mechanical site prep.	++	+	-	--
Prescribed burn	+	+	-	+
Pile and burn	+	+	-	--
Windrow and burn	+	+	-	-
Wildfire (hot)	++	++	--	--
Planted tree regeneration	0	+	+	0
Natural tree regeneration	0	+-	+	0

[1]Includes both ectomycorrhizal and free living, N-fixing bacterial activities based primarily in soil organic layers.

[2](+-) indicates effect depends on time, local conditions, or degree of treatment; (0) indicates no effect; (++ or --) indicates effect is very strong.

[3]For example, one-third and two-thirds stand density reduction (thinning) treatments described in STEM field site descriptions (this proceedings).

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Management and Economic Consequences

Chaired by: Robert E. Benson

The principal justification for harvesting in presently submarginal stands is to facilitate management of the stand, and to manage or influence other resources and uses on the site. Objectives relating to fire (fuels) management, wildlife habitat improvement, insect control, and other such concerns are typically integrated in the harvesting or thinning treatment prescription. The use of harvesting prescriptions and activities to achieve a combination of timber and nontimber management objectives raises questions of costs incurred and benefits achieved. In order to make valid decisions among treatment alternatives, managers need to be able to evaluate tradeoffs. Discussed in this section are some of the nontimber resource management concerns associated with harvesting in small lodgepole pine, and economic evaluation of alternative stand treatments.

PREDICTED RESIDUES AND FIRE BEHAVIOR IN SMALL-STEM LODGEPOLE PINE STANDS

James K. Brown and Cameron M. Johnston

ABSTRACT: Fuel loading, fireline intensity, and expected fire size were determined after harvesting small-stem lodgepole pine stands. Curves relating predicted fireline intensity to slash fuel loading and windspeed are presented. Removing about 15 tons per acre of residues reduced fireline intensity by half, but in some situations it still was too high to allow direct suppression. Effects of cutting level, method of felling, fuel removal, lopping, and slash age on expected fire size were evaluated. Commercial thinning with directional felling reduced expected fire size to that of undisturbed forest within 5 years. Nominal lopping was ineffective in reducing expected fire size. Methods for managers to use in appraising slash fuel hazard are reviewed. Economic analysis of fuel treatment is discussed.

INTRODUCTION

Thinning forest stands creates fuels of great concern to land managers. Wildfire in slash can be difficult to control and lead to development of large fires that are expensive to suppress. However, fuel quantities and fire behavior can vary substantially depending on the number and size of trees cut and on how the slash is treated after cutting. Appraisals of fuel and fire behavior potentials and the costs and benefits of treatment can help in determining the best alternative for managing fuels created by cutting.

Techniques developed over the past 15 years for appraising fuels and fire behavior potentials make possible mathematical and objective means to evaluate slash fuel problems. The purpose of this paper is to describe fuel quantities, potential fire intensity, and expected fire size resulting from various harvesting treatments that might be used in small-stem lodgepole pine stands. Management implications of the fuel and fire behavior appraisals due to various harvesting alternatives are discussed.

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PROCEDURES

Fuel and fire behavior were determined for small, overstocked stands of lodgepole pine predominantly 6 inches or less diameter at breast height (d.b.h.). A study of harvesting and silvicultural alternatives in small-stem lodgepole pine by the Intermountain Research Station Systems of Timber Utilization for Environmental Management (STEM) Program provided the stand conditions for predicting fuel loadings and fuel size distribution. Fire behavior predictions were based on fuel characteristics and varying fuelbed compactness levels that represent a wide range of stand treatment options. Some of these options were not a part of the STEM study. Expected fire size was determined for various combinations of fuel loading, lopping, directional felling, residue removal, and slash age.

Nineteen units in the Deerlodge, Lewis and Clark, and Gallatin National Forests were harvested by cutting approximately 33 and 66 percent of the live tree basal area. Another 14 units were designated as controls. Before cutting, stand conditions were:

	Low	High	Mean
No. trees per acre	860	9,400	5,110
Basal area (ft^2/acre)	125	260	200
Proportion of trees dead	0.12	0.41	0.26

Treatments called for felling and removing all harvest trees 3 inches and greater at the stump and for felling and slashing excess stems less than 3 inches at the stump. Whole trees were skidded by hand or cable to skid roads, then by rubber-tired skidders. Crawler or farm tractors were used to move the material to haul roads. Methods varied among the cutting units.

Fuel loadings were predicted using tree crown weight relationships (Brown 1978) contained in QDEBRIS, which is available through the Forest Service Northern Region shared computer library and managed by the Aviation and Fire Management Staff. Downed woody fuel loadings were also inventoried after the harvesting treatments using the planar intersect method (Brown 1974).

FIRELINE INTENSITY

Fireline intensity was predicted using the computer program HAZARD (Puckett and others 1979). Predicted total slash fuel loadings were entered in increments of 5 tons per acre. Average

d.b.h. of harvested trees on individual units ranged from 1.9 to 4.0 inches. Foliage and branchwood proportions vary only slightly over this d.b.h. range (Brown and others 1977); thus, an average d.b.h. distribution was used for all units to partition the total loading increments into 1-inch d.b.h. classes required to operate program HAZARD (fig. 1). Fuel moisture contents were the typical midsummer values in program HAZARD of 5, 7, and 9 percent for the 1-, 10-, and 100-hour timelag dead fuel classes.

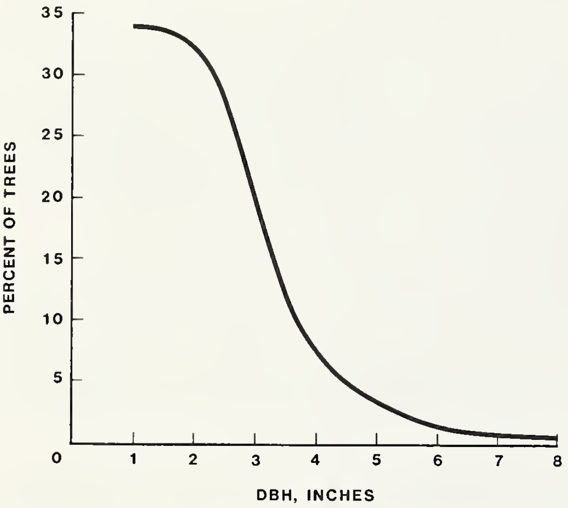

Figure 1--Average fraction of harvest trees by d.b.h. based on data from all harvested units.

Methods of felling, skidding, and lopping influence fireline intensity by altering fuel depth and, in turn, fuelbed compactness (Albini and Brown 1978). Fireline intensity was determined for two fuelbed compactness options:

1. Commercial thinning with directional felling and slashing of leave stems (fig. 2). This fuelbed represents relatively compact slash typical of ground-lead skidding. It applies to the STEM study harvested units where directionally felled stems were slashed every 6 feet or less and branches greater than 1 inch in diameter were lopped.

2. Precommercial thinning with felling in all directions (fig. 3). It was assumed that slash received nominal lopping, which leaves all branches within 2 feet of the ground and boles within 1 foot of the ground. This fuelbed has only slightly compacted slash; it is not compacted by equipment.

Fireline intensity was determined for 1-year-old and 5-year-old slash. One-year slash has all foliage attached to branches and is at maximum flammability. Five-year slash has lost most of its foliage and has settled considerably (Albini and Brown 1978). Five-year slash can be expected to remain flammable for 20 years or more.

Fireline intensity for the untreated control units was determined using the standard Intermountain Fire Sciences Laboratory (IFSL) Model 8 and 10, which correspond to National Fire-Danger Rating System (NFDRS) Fuel Models H and G, in the BEHAVE fire behavior prediction system (Andrews 1986). Model 8 represents nominal surface fuels in closed forest stands (Anderson 1982). Based on fuel inventories, it most nearly represents the untreated stands in the STEM study. Model 10 represents a heavy accumulation of surface fuels in closed forest stands that sometimes occurs in lodgepole pine.

Figure 2--This commercial thinning with directional felling and slashing of leave stems in lodgepole pine left 35 tons per acre of all-sized debris. It illustrates highly compacted slash typical of the STEM study treatments.

Figure 3--This precommercial thinning in grand fir (Abies grandis) left 40 tons per acre of all-sized debris. Although the slash was unlopped, the picture illustrates loosely arranged material characteristic of uncompacted or slightly compacted slash.

EXPECTED FIRE SIZE

The general approach to determining expected fire size and burned area is decision analysis (Howard 1973), which incorporates probabilities to deal with uncertainties about future fire occurrence, weather, fire behavior, and fire size. We determined expected fire size in a manner similar to the activity fuel appraisal process described by Hirsch and others (1981). They studied precommercial thinning on the Hungry Horse Ranger District, Flathead National Forest. Western larch, Douglas-fir, and Engelmann spruce were thinned to 200 stems per acre in 100-acre blocks distributed throughout a 10,000-acre stand. Interviews with District fire experts established the fire size estimates. They assumed that fire in unthinned stands would be easy to suppress but that fire in slash would be of high intensity and uncontrollable until it burned the slash.

Expected fire size is a probability-weighted average of all possible fire outcomes as shown in figure 4. It indicates average fire size given that a fire occurs. Expected acres burned annually for a specified management unit can be computed by multiplying expected fire size times fire occurrence rate. We used expected fire size as a measure of fuel hazard for comparing fuel treatments.

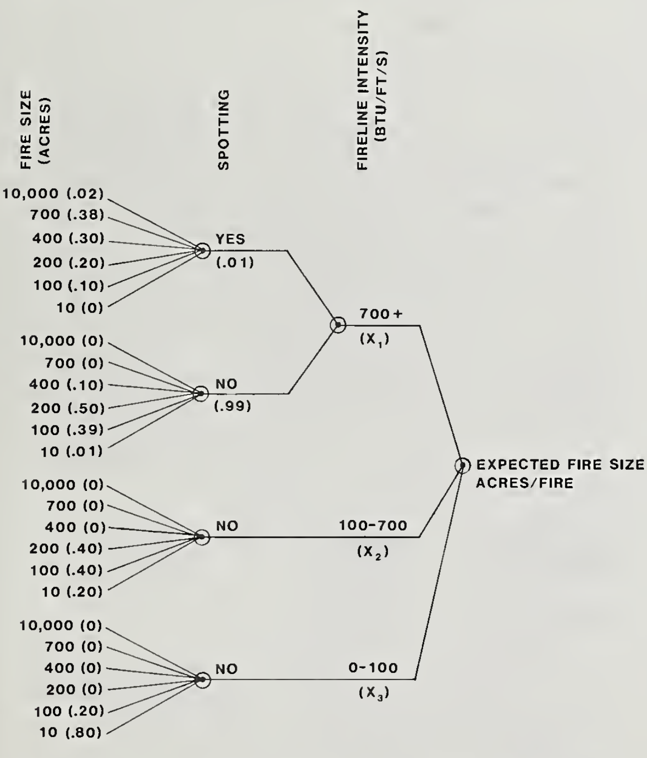

Figure 4--This decision tree summarizes events leading to expected fire size. Probabilities are in parentheses. The probability of an outcome (fire size) is the product of probabilities for all branches leading to the outcome. The expected fire size is the sum of all products of acres burned and their respective probabilities.

The decision tree in figure 4 was solved for the following stand treatment alternatives and fuel situations possible in small-stem lodgepole pine forests:

1. Unharvested stands represented by standard IFSL Fuel Model 8 (5 tons per acre of less than 3-inch diameter surface fuel) and Model 10 (10 tons per acre).
2. Precommercial thinning with random felling (felled in all directions or jack-strawed) --moderate cut (25 tons per acre).
3. Precommercial thinning with random felling--heavy cut (45 tons per acre).
4. Commercial thinning with random felling --moderate cut with trees greater than 2.5-inch d.b.h. removed (10.4 tons per acre after removal).
5. Commercial thinning with random felling --heavy cut with trees greater than 2.5-inch d.b.h. removed (18.4 tons per acre after removal).
6. Commercial thinning with directional felling--moderate cut with trees greater than 2.5-inch d.b.h. removed (10.4 tons per acre after removal).
7. Commercial thinning with directional felling--heavy cut with trees greater than 2.5-inch d.b.h. removed (18.4 tons per acre after removal).

All of the slash fuel models were evaluated by the decision tree in lopped and unlopped conditions and at 1- and 5-year ages.

The fireline intensities representing the different branches in figure 4 were based on general difficulty-of-suppression guides (Roussopoulos and Johnson 1975), explained later.

The probabilities for fireline intensity represented by X_1, X_2, and X_3 in figure 4 were determined for all fuel models and fire occurrence data from the Hebgen Lake Ranger District, Gallatin National Forest. The procedures involved:

1. Determining a cumulative probability distribution for the National Fire-Danger Rating System Burning Index for days that had fires in the lodgepole pine cover type (fig. 5). Burning Index was determined for 113 fire days from the 14-year period, 1970 to 1984.
2. Determining fuel moisture content and windspeed from weather records for days having Burning Index at the 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 0.9, 0.99 percentiles (table 1).
3. Computing fireline intensities using program HAZARD and the windspeed and fuel moisture data in table 1. Determining the cumulative frequency distribution of fireline intensity by plotting the fireline intensity values against the percentiles in table 1 (fig. 6).
4. Determining the probabilities (table 2), using figure 6, for the critical fireline intensity of 100 Btu/ft/s, which indicates the limit beyond which people are unable to work at the fire edge, and for 700 Btu/ft/s, which indicates the limit of direct attack (Roussopoulos and Johnson 1975).

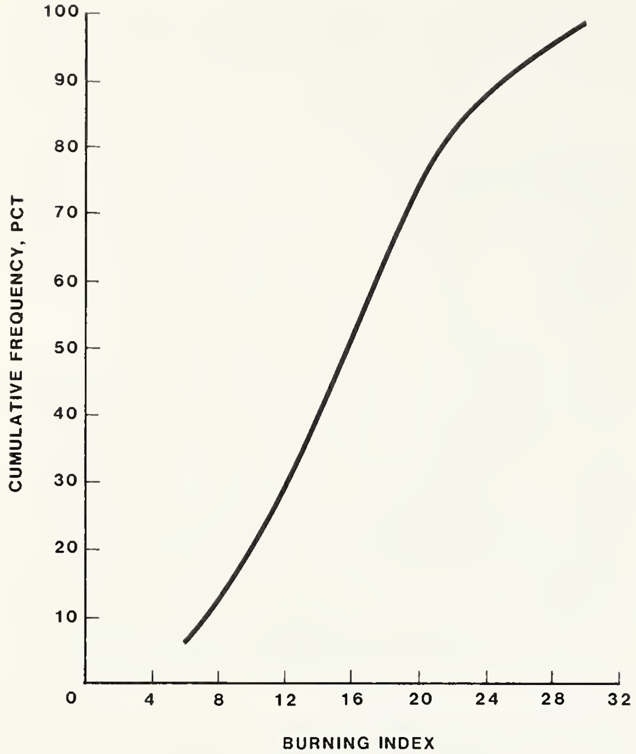

Figure 5--Cummulative frequency distribution for Burning Index on days with fires.

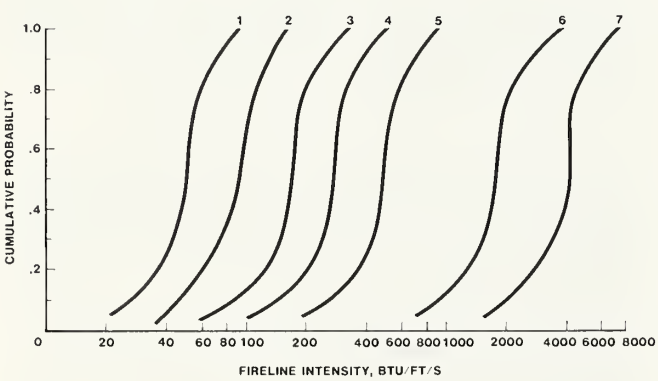

Figure 6--Cumulative frequency distribution of fireline intensity based on fire days for seven heavy cutting treatments and fuel conditions: (1) C--directional fell, lopped 5-year slash; (2) C --random fell, unlopped 5-year slash; (3) C--directional fell, lopped 1-year slash; (4) C--random fell, lopped 1-year slash; (5) C--random fell, unlopped 1-year; (6) P--random fell, lopped 1-year slash; (7) P--random fell, unlopped 1-year slash. Abbreviations are: C--commercial thinning, and P--precommercial thinning.

FUEL QUANTITIES

Harvesting created considerable amounts of fuel on most units (table 3). We predicted an average of 11 tons per acre more woody fuel for 66 percent harvesting of initial basal area than harvesting 33 percent of initial basal area. However, postharvest inventories indicated only a small difference in loadings between the 33 and 66 percent basal area levels. Apparently, more residues were removed on the heavier thinning treatments.

The difference between predicted and inventoried fuel quantities in table 3 is largely due to fuel removed and to unknown quantities of preharvest downed woody fuel. Deducting inventoried fuels from predicted residues plus preharvest fuels (average of control plots) indicates that an average of 13 tons per acre of woody fuel was removed by operators. Another 2 tons per acre of foliage, which averaged 18 percent of less than 3-inch woody residues, was probably removed. However, removal varied considerably by operator, ranging from about 7 to 20 tons per acre. Fuel depth was low, averaging 6 inches for all units. This depth and the average fuel loading (table 3), adjusted to include foliage, yielded an average fuelbed bulk density of 2.0 lb/ft^3, which is 2.5 times more compact than assumed in the precommercial thinning fuelbed option.

FIRELINE INTENSITY

Curves of fireline intensity are shown for commercial thinning slash (fuelbed option 1) at 1 year of age (fig. 7) and for precommercial thinning slash (fuelbed option 2) at 1 year of age (fig. 8) and at 5 years of age (fig. 9). These curves can be used to predict potential fireline intensities based on fuel loadings under dry summertime conditions. Fireline intensity, which is the heat produced from a unit width cross section of the propagating flame front, is probably the most useful characteristic of fire behavior for evaluating slash fuel hazard. The fireline intensity relationships in figures 7, 8, and 9 can be used to appraise the difficulty of suppression based on the following guides (after Roussopoulos and Johnson 1975):

Fireline Intensity	Flame Length	Fire Situation
(Btu/ft/s)	(Ft.)	
<5	<1	Marginal burning. Few fires exist at this level.
20 to 50	2 to 3	Easily attacked and controlled. People can work right up to the edge of the fire without protection.

Table 1--Windspeed and fuel moisture content for days having Burning Index at specified cumulative frequencies (fig. 5)

Variable	Percentile							
	0.05	0.1	0.2	0.4	0.6	0.8	0.9	0.99
Windspeed at 20 ft, mi/h	5	5	7	8	8	9	10	11
Fuel moisture, percent								
1-hour timelag	14	10	8	7	6	6	5	4
10-hour timelag	17	17	12	9	7	6	5	4
100-hour timelag	18	17	14	12	12	11	9	8
1,000-hour timelag	30	25	21	19	14	14	13	12

Table 2--Probabilities of specified fireline intensities for various fuel models and fuel conditions determined from cumulative frequency distributions of fireline intensity (fig. 6). Abbreviations are: PC--precommercial thinning, and C--commercial thinning

Fuel model	Nominal lopping	Fireline intensity (Btu/ft/s)		
		0 to 100	101 to 700	700+
One-year-old slash				
PC - random fell, moderate	no	0	0.05	0.95
PC - random fell, moderate	yes	0	.16	.84
PC - random fell, heavy	no	0	0	1.0
PC - random fell, heavy	yes	0	0	1.0
C - random fell, moderate	no	.075	.925	0
C - random fell, moderate	yes	.175	.825	0
C - random fell, heavy	no	0	.94	.06
C - random fell, heavy	yes[1]	.05	.95	0
C - directional fell, moderate	yes[1]	.80	.20	0
C - directional fell, heavy	yes[1]	.14	.86	0
Five-year-old slash				
PC - random fell, moderate	no	.05	.95	0
PC - random fell, moderate	yes	.05	.95	0
PC - random fell, heavy	no	0	.94	.06
PC - random fell, heavy	yes	0	.94	.06
C - random fell, moderate	no	1.0	0	0
C - random fell, moderate	yes	1.0	0	0
C - random fell, heavy	no	.65	.35	0
C - random fell, heavy	yes[1]	.65	.35	0
C - directional fell, moderate	yes[1]	1.0	0	0
C - directional fell, heavy	yes[1]	1.0	0	0
Undisturbed				
IFSL Model 8	-	1.0	0	0
IFSL Model 10	-	.175	.825	0

[1]More compact than nominal lopping because stems are slashed every 6 feet and branches 1 inch or greater in diameter are lopped.

Table 3--The mean and range of inventoried and predicted fuel quantities for control plots and plots harvested by removing 33 and 66 percent of initial basal area (Ba)

Estimate	Woody fuel size	Low	High	Mean[1] 33 percent	66 percent	All
	Inches	Tons per acre				
Inventory						
Postharvest	0 to 3	6.2	35.6	17.6	20.5	18.9
Postharvest	3+	.4	7.7	3.0	3.5	3.2
Control	0 to 3	.9	10.6	--	--	5.3
Control	3+	0	18.1	--	--	3.7
Prediction						
Residue	0 to 3	8.7	44.4	21.7	32.3	26.7
Residue	0 to 3 and foliage	11.1	55.8	26.2	39.4	32.4

[1]Number of plots were control = 14; 33 percent Ba/acre = 10; and 66 percent Ba/acre = 9.

Fireline Intensity	Flame Length	Fire Situation
100	4	This is about the limit beyond which people are unable to work at the fire edge.
500 to 700	8 to 9	Spotting begins to be a problem and the limit of direct attack is probably reached in this range of intensities.
1,000	11	Crowning can be expected to begin. Serious spotting may occur.
20,000 to 30,000	40 to 50	Major conflagration. Long-range spotting occurs. Tree blowdown may occur. Flaming zone depths of up to one-fourth mile can arise.

Fireline intensity for a fuel loading of 20 tons per acre, which was nearly the average for the 33 and 66 percent basal area removal treatments (table 3), entered the 500 to 700 Btu/ft/s hazard band at the following windspeeds (figs. 7, 8, and 9):

Fuelbed	Windspeed (Mi/h)
Commercial thinning 1-year slash	12
Precommercial thinning 1-year slash	4
Precommercial thinning 5-year slash	17

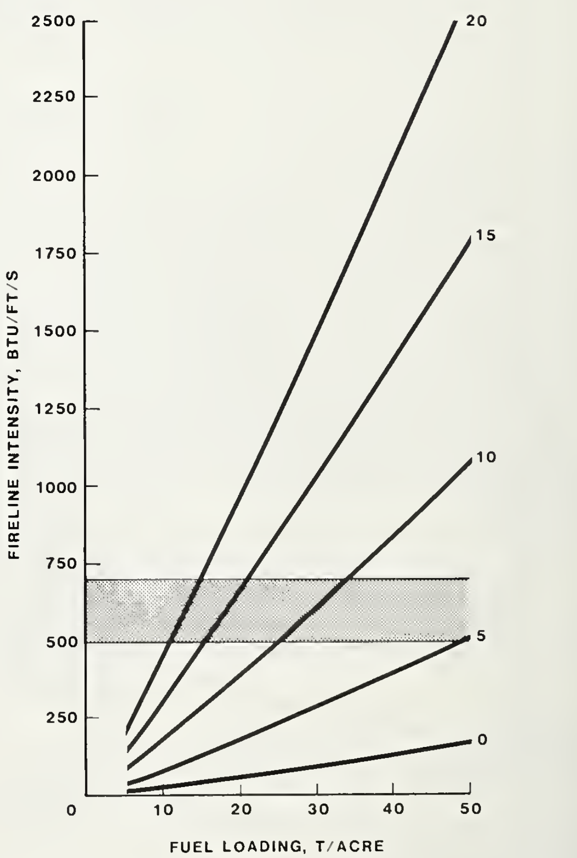

Figure 7--Fireline intensity for the commercial thinning 1-year-old lodgepole pine residue loadings (foliage and branchwood less than 3 inches diameter) by 5 mi/h windspeed intervals at 20 feet above ground. The shaded band indicates the lower limits of difficult fire suppression.

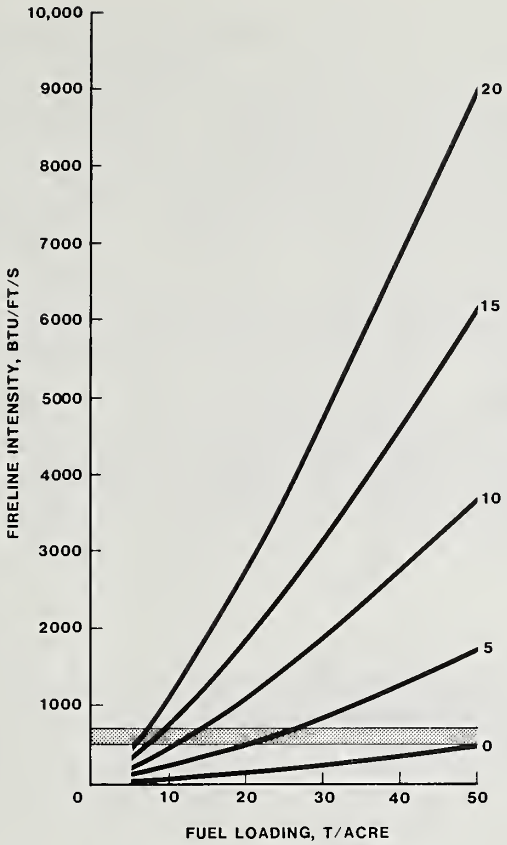

Figure 8--Fireline intensity for the precommercial thinning option 1-year-old lodgepole pine residue loadings (foliage and branchwood less than 3 inches diameter) by 5 mi/h windspeed intervals at 20 feet above ground. The shaded band indicates the lower limits of difficult fire suppression.

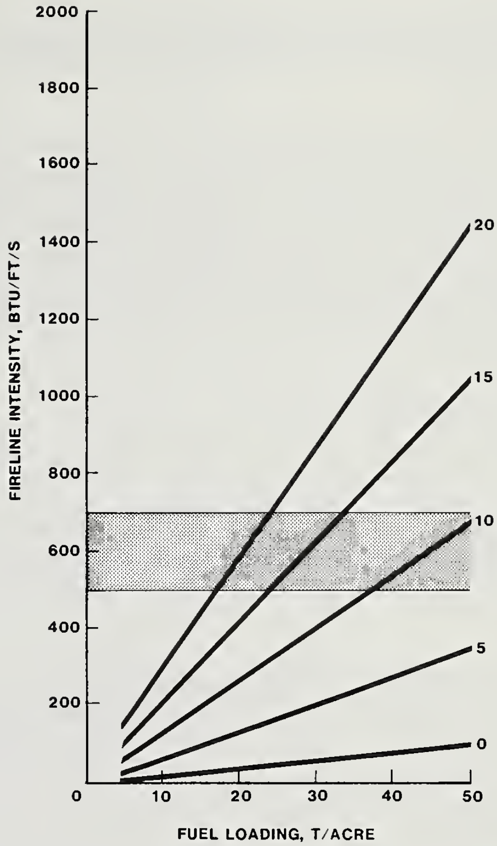

Figure 9--Fireline intensity for the precommercial thinning option 5-year-old lodgepole pine residue loadings (foliage and branchwood less than 3 inches diameter) by 5 mi/h windspeed intervals at 20 feet above ground. The shaded band indicates the lower limits of difficult fire suppression.

Certainly, windspeeds of 4 and 12 mi/h occur frequently and a windspeed of 17 mi/h occurs occasionally in most areas. Thus, the 20 tons per acre fuel loading represents hazardous fire behavior potential on some to many days during the summer. Hazard at higher loadings, of course, is increased (figs. 7, 8, and 9).

In commercial thinning, removing trees 3 inches in diameter and larger at stump height reduced predicted fireline intensity to half of the potential if all residues had remained on site. However, the removal of trees still left potential fireline intensities that exceeded capabilities for direct fire suppression at commonly occurring windspeeds. In whole-tree skidding of commercial-size Douglas-fir and western larch, fireline intensity was reduced approximately four times from the potential created by all fuels remaining on site (Brown 1980).

In precommercial thinning, loadings of less than 3-inch fuel that are less than 15 to 20 tons per acre will be below hazardous levels in about 5 years (fig. 9). Appraisal of 5-year-old slash may be most appropriate for deciding upon hazard abatement activities because the fire behavior potential will likely persist for 20 or more years. Although hazard is greater in 1-year-old slash, it only persists at higher levels for 1 to 3 years.

Applying figures 7, 8, and 9 to harvested, small-stem lodgepole pine stands requires judgment. The commercial thinning option best represents fuelbed compactness created by directional felling and slashing of unremoved stems. It should provide reasonable estimates for 1- and 2-year-old slash (fig. 7). Figure 8 should apply best to 1- and 2-year-old precommercially thinned slash. However, for appraising all slash 5 years and older, the precommercial thinning option should be assumed (fig. 9). Accuracy of predicted fireline intensity for 5-year-old slash under the commercial thinning option is uncertain. We suspect that the commercial thinning option would probably substantially underpredict fireline intensity. Certainly, total fire intensity, which includes flaming combustion within and behind the propagating fire front, would probably greatly exceed predicted fireline intensity. The mathematical model used to predict fireline intensity was based on combustion of fine fuels (Rothermel 1972). After foliage has fallen, a fuelbed of small-stem lodgepole pine slash is largely composed of tightly compacted woody fuel greater than one-half inch in diameter. Prolonged

burnout of woody fuel results. These fuel conditions are beyond the scope of current fire behavior modeling. Predictions of fireline intensity in tightly compacted fuelbeds are untested.

Few trees would survive fire in harvested, small-stem lodgepole pine stands. For example, at 300 Btu/ft/s, which is easily reached (figs. 7, 8, and 9), a 5-inch d.b.h. lodgepole pine tree has less than a 10 percent chance of surviving fire (Reinhardt and Ryan in press). Smaller trees would have essentially no chance of surviving fire and larger trees only a slightly better chance.

EXPECTED FIRE SIZE

Expected fire size provides a means to compare fuel treatment effectiveness. Determining expected fire size is a necessary step in evaluating the effect of fire on resource production and for assessing operational costs.

Removal of fuel by commercial thinning and directional felling effectively reduced expected fire size from that of precommercial thinning (table 4). Expected fire size in commercially thinned 1-year slash with directional felling was substantially less than that with random felling for moderate loadings, but not for heavy loadings. However, at heavy loadings in 5-year slash, directional felling resulted in a smaller expected fire size than random felling. In 5-year slash at moderate loadings, there was no difference between felling methods. For several commercial thinning situations, expected fire size was reduced to undisturbed levels within 5 years (table 4).

Nominal lopping reduced fireline intensity, but not enough to affect difficulty of fire suppression. For example, lopping reduced fireline intensity to below 700 Btu/ft/s only at windspeeds of less than 5 mi/h for the precommercial thinning model at moderate fuel loading. Thus, at windspeeds greater than 5 mi/h,

Table 4--Expected fire size determined for cutting and undisturbed fuel treatments. Abbreviations are: PC--precommercial thinning and C--commercial thinning. Numbers in parentheses are expected fire sizes normalized to Fuel Model 8

		Slash age and loading				
		1-year		5-year		
Fuel model	Lopping	Moderate	Heavy	Moderate	Heavy	Nonslash
		Acres				
Cutting						
PC, random fell	no	181 (6.5)	184 (6.6)	117 (4.2)	126 (4.5)	
PC, random fell	yes	174 (6.2)	184 (6.6)	117 (4.2)	126 (4.5)	
C, random fell	no	115 (4.1)	126 (4.5)	28 (1.0)	61 (2.2)	
C, random fell	yes	106 (3.8)	117 (4.2)	28 (1.0)	61 (2.2)	
C, directional fell	yes[1]	47 (1.7)	109 (3.9)	28 (1.0)	28 (1.0)	
Undisturbed						
Model 10						106 (3.8)
Model 8						28 (1.0)

[1]More compact than nominal lopping because stems are slashed every 6 feet and branches 1 inch or greater in diameter are lopped.

difficulty of fire suppression was not significantly changed.

For precommercial thinning and some commercial thinning situations, expected fire size was nearly the same at heavy and moderate fuel loadings. In other commercial thinning situations, expected fire size differed between moderate and heavy loadings due to method of felling (table 4).

The accuracy of fire size predictions in this analysis is unknown. Estimates are probably high for harvesting in small-stem lodgepole pine, primarily because it was assumed that all fires were burning during midday when weather readings are normally taken. Some fires, however, start at night and are put out before afternoon. Nonetheless, the relative differences in fire size between harvesting treatments should be meaningful.

METHODS FOR APPRAISING SLASH HAZARD

Procedures for estimating fuel quantities and fire behavior potential are available for appraising slash hazard on specific land units. Land managers who wish to appraise slash hazard should first decide how accurately they need to know fuel quantity and fire behavior potentials. Then, one of the following methods can be used to help appraise slash hazard.

1. Nomographs of rate of spread, fire intensity, and flame length--Using nomographs developed by Albini (1976), fire behavior at variable fuel moisture and windspeed can be predicted for low, medium, and heavy logging slash. These nomograms were developed for slash left after logging to an 8-inch top and skidding using a ground-lead system. Precision in the fire behavior estimates is relatively broad since the method recognizes only three levels of fuel quantity.

2. Photo series--A series of photographs depicting a wide range of slash conditions identified by estimates of fuel loadings and fire behavior ratings was developed by Koski and Fischer (1979) for thinning slash in northern Idaho, and by Maxwell and Ward (1978a, 1978b) for forest residues in Washington and Oregon. These photos in field manual editions can be compared with existing slash accumulations. By selecting the photo that most nearly compares with what is seen on the ground, one can estimate fuel loading and fire behavior potentials. This method affords more resolution of predictions than the nomograph method, but its accuracy is unknown and probably somewhat limited. The method is appropriate where the more accurate methods are not available or needed.

3. Computer analysis using program HAZARD--Estimates of head-fire spread rate, perimeter growth rate, flame length, crown scorch height, fireline intensity, and other fire characteristics can be obtained using computer program HAZARD, which can be accessed through the USDA Computer Center at Fort Collins, CO. Procedures for making the hazard assessment are described in Fuel Treatment Guides, published by the Northern Region (Puckett and others 1979) and Pacific Northwest Region (Snell and others 1979) of the Forest Service.

Operation of the HAZARD program requires estimates of down woody fuels existing before cutting, and debris expected from cutting. If necessary, existing fuels can be inventoried using the planar intersect method (Brown 1974). (In the Northern Region, the same information can be obtained from the down fuel inventory done in conjunction with the Northern Region Stand Examination). Expected quantities of debris can be estimated using tables developed by Brown and others (1977) or by using a computer program called QDEBRIS. This program furnishes predictions of debris from timber stand inventories and from Northern and Pacific Region sale cruises.

Of all current methods, HAZARD provides maximum resolution and accuracy with the least amount of user interaction. Program HAZARD has built in functions that determine proper fuel depth and effects of slash aging.

4. Computer analysis using BEHAVE--BEHAVE is an interactive computer system for predicting fire behavior characteristics (Andrews 1986). The complete system, which includes fuel modeling, is available on most Forest Service Data General computers at the National Forest level, and at the USDA Fort Collins Computer Center. BEHAVE will estimate fire spread rate, intensity, probable flame length, containment time, and final fire size. To do this requires information about fuels, weather, time, overstory, fuel moisture, and position of the fire on a slope. BEHAVE features a method to aid in development of site-specific fuel models if the 13 standard fuel models cannot be used (Burgan and Rothermel 1984).

5. Computer analysis using the national fuel appraisal process-- This is a quantitative process for appraising fire hazard of residue fuels. This process combines fire and fuel modeling with decision analysis principles to produce an estimate of expected burn area. Expected fire occurrence, climate, fuel loads, fire behavior, and suppression capability are considered in the fuel appraisal process. The process has 12 steps described in a User's Guide to the National Fuel Appraisal Process (Radloff and others 1982). This appraisal process, related to Forest Service activities, is also described in the Fire Management Analysis and Planning Handbook (USDA Forest Service 1985).

SELECTING A FUEL TREATMENT OPTION

An important and often difficult question is what fuel treatment options, including no treatment, are justified? The question is basically are the benefits of fuel removal, mechanically or by fire, greater than the costs? The answer depends on many site-specific factors. An approach to answering the question by systematically evaluating how much fuel is acceptable is suggested by Brown (1980). The process requires

systematic consideration of fire behavior potential over treated and surrounding untreated areas, effects on resource values, management objectives, pattern of land ownership, and suppression capability.

ECONOMIC ANALYSIS

A method of analysis subscribed to in several studies of fuel treatment options and described in the Fire Management Analysis and Planning Handbook (USDA Forest Service 1985) involves determining fire program costs plus net resource value change. This analysis requires knowledge of expected annual area burned for all fuel treatment options, costs of the fire program with and without fuel treatment, and values of resources with and without fuel treatment.

Using this type of analysis to evaluate management of nonslash fuels in the Lolo National Forest, Wood (1979) concluded that fuel treatment to protect the timber resource alone (by reducing the number of class E and bigger fires) was not economically feasible. In a detailed analysis of fuels, fire behavior, and expected burn area for a ponderosa pine forest in Arizona, Hirsch and others (1979) found that treatment of only sawtimber slash was preferred. Only timber values were considered. They also noted that incorporating more resource values could change the selection of a fuel treatment. In a case study of fire management and fuel treatment decisions involving commercially valuable Douglas-fir in the Mount Hood National Forest, Barrager and others (1982) found that, under a wide range of assumptions, no fuel treatment was the best alternative. They drew two possible conclusions:

1. Direct resource benefits of fuel treatment such as enhanced water, wildlife, and other resource values are underestimated, or;
2. Much more fuel treatment is being carried out than is economically feasible.

These studies have shown that (1) benefits other than commercial timber products can strongly influence the outcome of economic analyses, and (2) fuel treatment may be justified on high-value timber sites but is difficult to justify on low-value sites.

Although none of these studies dealt specifically with harvesting small-stem lodgepole pine, they do suggest that fuel treatment in partially cut lodgepole pine stands would be difficult to justify economically, primarily because of low timber values and low fire occurrence rates.

Analyses of costs plus net value change provide an objective basis for deciding upon fuel treatment options. Limitations to these analyses usually involve the inability to objectively describe all important factors. One factor that is difficult to evaluate is the chance of a very large fire with uncertain threat to lives. Regardless of the degree of quantification in evaluating fuel treatment options, experience and judgment are required for both technical considerations and to interpret social/political concerns.

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EFFECTS OF THINNING SMALL-STEM LODGEPOLE PINE STANDS ON BIG GAME HABITAT

L. Jack Lyon

ABSTRACT: Acceptable habitat for Rocky Mountain elk is generally considered to require combinations of hiding cover, thermal cover, and foraging areas. In this study, untreated lodgepole pine stands provided high levels of hiding and thermal cover. Thinning at any level reduced these values; with 66 percent basal area removal, the losses were substantial. Based on the predicted growth of treated stands, thermal cover values will eventually be regained, but hiding cover will not. The 66 percent treatment could possibly result in an understory response that will increase forage production; but the 33 percent and untreated stands are unlikely to have productive understories. Evaluation of these changes on habitat quality for elk would require information about stand juxtaposition and arrangement.

INTRODUCTION

Thinning timber stands, although it will not usually produce as complete a change in the forest environment as final harvest logging, nevertheless is recognized as having potentially important influences on the quality and productivity of forest wildlife habitats. Evaluating those influences will not produce any equivocal judgment in a positive or negative sense. Some results are likely to be beneficial, while others will certainly be negative. In this presentation, I discuss some possible effects on big game habitat of thinning in small-stem stands of lodgepole pine.

In recent years, methods of evaluating habitat quality for big game animals have become increasingly precise because managers have been able to evaluate existing habitat against relatively standard criteria that represent high-quality habitat. The Rocky Mountain elk has achieved prominence as a representative big game species because elk habitat models are generally similar to each other and are widely used by western National Forest personnel. Although there are variations in the ways model results are used and interpreted, there is a consistency in the fact that all models presume the necessity for hiding cover, thermal cover, foraging areas, and for appropriate juxtaposition of cover areas and foraging areas.

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HABITAT DEFINITIONS

Acceptable habitat for Rocky Mountain elk is generally considered to require combinations of hiding cover, thermal cover, and foraging areas. An optimal arrangement might include ". . . 20-percent hiding cover, 10-percent thermal cover, 10-percent hiding or thermal cover, and 60-percent forage areas" (Thomas and others 1979, p. 121). The values of interest are defined as:

> Hiding Cover--vegetation capable of hiding 90 percent of a standing adult elk from the view of a human at a distance of 200 feet or less.
>
> Thermal Cover--any stand of coniferous trees 40 feet or more in height and with an average canopy closure exceeding 70 percent.
>
> Foraging Area--any vegetated area that does not satisfy the criteria for cover.

Using these definitions, one can take a relatively straightforward approach to evaluating the influence of thinning in individual small-stem timber stands. The presumptions made are that management activities in an existing timber stand modify the cover values of the stand and may possibly convert the stand to a foraging area.

DATA EVALUATION

Data from 60 lodgepole pine stands examined in the Systems of Timber Utilization for Environmental Management (STEM) study were used in developing estimates of hiding and thermal cover. Included were stands thinned to 33 and 66 percent of previous basal area and untreated stands. Evaluation procedures were:

Hiding cover--In mature lodgepole pine stands, the hiding cover value is primarily determined by visual obstruction by individual tree stems. This value can be calculated with the computer program HIDE2 on the Forest Service Northern Region mainframe computer or in a BASIC version for IBM-compatible personal computers, (Lyon 1985). Input to the program is the stand structure indicated by stem diameters and densities. Output is the calculated percentage of hiding cover for elk. When this estimated value is less than 90 percent, it indicates some cover, but less than required to classify the entire stand as hiding cover.

Thermal cover--Actual canopy cover in the sample stands was not measured during the STEM study, but

several options were available for calculating the canopy closure values. For pretreatment stands, I used the basal area formula developed for lodgepole pine by Dealy (1985):

Percent crown closure = -20.29+41.80(Log10(BA+1))

For the immediate posttreatment stands, when crown diameters were still likely to have been influenced by pretreatment densities, I used the average crown diameter and density figures supplied by the STEM study. And for posttreatment stands predicted at 120 years, whether treated or untreated, I used Dealy's formula.

Foraging area--Any stand that does not provide 90 percent hiding cover or have 70 percent canopy closure is, by definition, a foraging area. However, there may be some hiding and thermal values present in many stands that do not fully satisfy these criteria. Where some cover values remain, forage production usually is reduced in proportion to the amount of cover remaining. It is also generally recognized that many of the forest types in which lodgepole pine is dominant do not necessarily produce substantial understory responses when crown cover is reduced.

DATA ANALYSIS

Analyses consisted primarily of determining mean values and ranges for hiding cover and thermal cover for stands in various treatment categories. In addition, each data set was examined with the regression program REX using basal area, stem density, and stem diameter as predictors of cover values. REX computes all possible combinations of the three variables and selects the combination that yields the smallest residual mean square. Interpretation of this analysis is obviously confounded by the strong correlations among the three variables, but a useful purpose is nevertheless served if the range of predicted cover values is not overly narrow. For most treatments it was possible to determine the minimum set of values adequate to satisfy cover definitions.

RESULTS

Pretreatment data were available for 60 stands. In 30 stands treatment was completed and predictions of future growth were made. Appropriate estimates of hiding cover and thermal cover were made for four categories of data: pretreatment; immediate posttreatment; treated, 120 years; and untreated, 120 years. The projection to 120 years was selected as adequately representative of growth responses expected in these stands. Means presented in table 1 represent all replications of the same treatment for both hiding cover and thermal cover calculations.

Hiding Cover

Pretreatment--Stem density was under 1,000 per acre in only two of the untreated stands and under 2,000 per acre in an additional six stands. For these eight stands, hiding cover averaged 57.7 percent. No stand with 2,300 or more stems had less than 90 percent hiding cover. The minimum values required to supply hiding cover were about 160 ft^2 basal area and 2,300 stems per acre.

Table 1--Hiding cover and thermal cover values calculated for lodgepole pine stands of the STEM study

Treatment category	Samples	Hiding cover	Thermal cover[1]
	Number	Percent	Percent
Pretreatment	60	93.3	75.8
Immediate posttreatment			
33 percent	15	48.0	54.9
66 percent	15	11.9	29.2
Treated, 120 years			
33 percent	15	48.8	70.8
66 percent	15	24.0	66.6
Untreated, 120 years	30	77.5	73.0

[1]Mean crown widths of residual trees were measured in most plots. Averages for 33 and 66 percent posttreatment canopy cover were 5.1 and 5.7 feet, respectively. For pretreatment and predictions, canopy closure was calculated by formula (Dealy 1985).

Posttreatment--Following removal of 33 percent basal area, an average of 48.0 percent hiding cover remained. This figure is somewhat deceiving, however, because actual cover values in the treated stands ranged from 9.7 to 97.8 percent. At least 110 ft^2 of basal area and 1,100 stems per acre are required to retain even 50 percent hiding cover. Removal of 66 percent basal area was relatively consistent in reducing hiding cover to an average 11.9 percent, although treatments in which 1,000 stems per acre remained had about 30 percent cover.

Predicted--The average stem diameter with 33 percent removal is predicted to rise from 4.5 to 6.3 inches, but tree densities will decline from about 1,200 to 800 per acre. Hiding cover in these stands will average 48.8 percent. In the 66 percent removal stands, hiding cover is predicted to rise to approximately 24 percent at 120 years. With the increase in average stem sizes in these stands, a minimum basal area of 160 and density of 900 stems per acre are required to produce 50 percent hiding cover.

In the absence of any treatment, hiding cover is predicted to decline to approximately 78 percent. However, this prediction is based on live stems only. There is a relatively high expectation that standing dead stems would actually produce hiding cover values approximating those of the pretreatment stands.

Thermal Cover

Pretreatment--Crown canopy closure in the untreated stands ranged from 60.7 to 86.5 percent, but only 12 stands were under 70 percent and just one under 65 percent closure. Any basal area greater than 140 is likely to have 70 percent or greater canopy closure and thus satisfy thermal cover standards.

Posttreatment--Reductions in canopy cover to about 55 percent following 33 percent basal area removal, and to 29 percent following 66 percent basal area removal, were relatively consistent in all treated stands. Any basal area greater than 128 ft^2 will have at least 50 percent thermal cover remaining, but the immediate posttreatment stands will only rarely have as much as 70 percent canopy.

Predicted--When enough time has passed for tree crowns to fill out into the space made available by thinning, stands of the 33 percent treatment will average about 71 percent canopy and the 66 percent treatment stands will reach 67 percent canopy. In either treatment, 148 feet of basal area is predicted to produce 70 percent crown closure. Stands with lesser basal areas will have much lower canopy closure values.

Treated and untreated stands would become virtually identical over the range of time used for this prediction. Data for the untreated stands suggest that any basal area greater than 146 ft^2 will produce 70 percent crown closure at 120 years.

Foraging Areas

No data were available to provide a direct demonstration of forage production changes in the stands of the STEM study. Nevertheless, some evaluation of probable foraging values is suggested by the crown canopy information and at least partially confirmed by field inspection. Before treatment, virtually every stand had 70 percent or greater canopy closure. Any treatment providing more light to the forest floor could be expected to increase understory production--but only in situations where an understory plant community already exists. It should be recognized that thinning, unlike complete removal, provides little disturbance and little opportunity for establishment of new plants. Where a duff and needle cover and few understory plants are present, no increases in forage production can be expected.

Based on averages, only the treatments with 66 percent basal area removal were considered likely to increase forage production. Lesser treatments did not reduce canopy closure below 50 percent, and understory responses to such minor increases in light are likely to be too subtle to be detected. Moreover, even the 66 percent treatment left enough tree crowns to block out a fourth of the available light.

Other Considerations

Shrubs as hiding cover--Tall shrubs appeared to provide hiding cover where they were present. However, only three stands in the STEM study had tall shrubs. The data presented in table 2 make it clear that presence of any shrub species tall enough to provide hiding cover in lodgepole pine stands can make an important contribution. At the shrub densities recorded, hiding cover was increased to over 90 percent in virtually every treatment situation.

Slash disposal--A final consideration in evaluating the influence of thinning on habitat quality for big game involves the disposal of the cut materials. In the STEM study, all of the cut material over 3 inches in diameter was removed. Some was utilized for grape stakes, corral poles, or other purposes. When such material is not removed or treated, it can become an obstruction to big game use of the thinned stands. Lyon and Jensen (1980) showed that 1.5 feet of untreated slash in clearcut openings will reduce elk use by 50 percent. Similar, or even greater, losses of potential use by big game can be expected when slash remains in thinned stands. Failure to remove slash will also result in substantial reductions in expected production by understory plants.

DISCUSSION

Older lodgepole pine stands generally achieve status as cover for big game on visual blockage by stems alone. Any stem density greater than 2,300 per acre or basal area over 160 ft^2 probably represents hiding cover; any basal area greater than 140 ft^2 almost certainly has the 70 percent crown closure required for thermal cover.

Removal of stems from these stands reduces hiding cover and thermal cover values and may increase forage production. Hiding cover, in particular, can relatively easily be reduced to less than acceptable levels for big game. Any influence these changes might have on the quality of big game habitat, however, is determined by the already existing proportions of hiding cover, thermal cover, and foraging areas in the environment. Where cover is in excess, conversion of dense stands of trees to more productive foraging areas has some potential for improvement of habitat quality. Successful conversion depends on selecting stands with already existing understory vegetation and removing enough of the thinned material to assure the treated stand will not be avoided by game animals.

Table 2--Hiding cover contribution of shrubs in three lodgepole pine stands of the STEM study

Area and shrub component	Hiding cover: Without shrubs	Hiding cover: With shrubs
	Percent	
Ballard Hill North: 48 Willow, 48 Alder		
Pretreatment	98.9	100.0
Posttreatment plus 8 years		
33 percent	75.9	94.8
66 percent	5.2	79.3
Treated, 120 years		
33 percent	56.9	89.7
66 percent	19.0	86.2
Untreated, 120 years	81.1	96.6
Echo Lake: 16 Willow, 89 Alder		
Pretreatment	100.0	100.0
Posttreatment plus 8 years		
33 percent	67.2	96.6
66 percent	12.1	93.1
Treated, 120 years		
33 percent	62.1	94.8
66 percent	39.7	96.6
Untreated, 120 years	99.2	100.0
Dry Creek West: 138 Maple		
Pretreatment	100.0	100.0
Posttreatment plus 8 years		
33 percent	44.8	100.0
66 percent	5.2	93.1
Treated, 120 years		
33 percent	43.1	96.6
66 percent	39.7	93.1
Untreated, 120 years	88.0	99.2

These calculations were based on the assumption that average plant width is determined by the shrub species tolerance in competition for light. Five overstory conditions assumed the following average shrub widths (in feet):

Species	Pre-treatment	Post-treatment	Treated 33%	Treated 66%	Untreated
Willow (SASC)	2	5	2	3	2
Alder (ALSI)	8	4	6	6	8
Maple (ACGL)	3	5	4	5	3

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ECONOMIC EVALUATION OF ALTERNATIVE LODGEPOLE PINE STAND TREATMENT EFFECTS ON TIMBER AND NONTIMBER RESOURCES

Robert E. Benson

ABSTRACT: More than 30 cutting units in 15 lodgepole pine pole-size stands were used as a basis for analyzing the economic and other management consequences of alternative harvesting practices. Net dollar values are an important part of such economic analyses, and these values were computed for the study sites. Observed treatment costs and recovered values, and several simulations, were used with projections of future stand growth in the analyses. Although most stand treatments were economically marginal or submarginal, some showed positive future values. Wildlife habitat and scenic quality were significantly influenced by stand treatments, with heavier cutting levels generally being least desirable.

INTRODUCTION

As part of the Systems of Timber Utilization for Environmental Management (STEM) program of research in harvesting and utilization alternatives for marginal timber resources, young overstocked stands of lodgepole pine were treated using 33 percent and 66 percent basal area reduction partial-cut prescriptions, as well as clearcutting. This paper evaluates the economic aspects of these harvesting alternatives, and the relationship to timber and nontimber resource management considerations.

Of 25 areas identified as representing young, overstocked lodgepole pine stands in the Northern and Intermountain Forest Service Regions, 23 areas were contracted for harvesting. Of these, 15 areas composed of 33 treatment subunits were completed in time for this initial summary of harvesting. Eleven areas, with 25 treatment subunits, had harvest cost and recovered product value data that were suitable for analysis of timber values. The other eight harvested subunits contributed volume and stand stocking data that are used in some parts of the analysis that follows. The analysis of timber and nontimber resource effects includes consideration of esthetics, wildlife habitat, and potential growth and losses in stands that have been thinned.

ANALYSIS OF TIMBER VALUES

The stands harvested at the study sites are representative of many situations where posts and poles are commercially harvested. However, research study requirements resulted in several important operational differences. Thinning was based on applying prescribed percent reductions in preharvest basal area, removing smaller trees and leaving dominant-codominant trees in the residual stands. As a result, there was wide variation in the amount and type of material removed, and in postharvest spacing of the residual stands. All cut material 3 inches and larger at the stump, live or dead, was required to be removed from the stand even if it was not considered merchantable by the operator. No mechanical equipment was allowed inside the stand for skidding; most material was removed by hand or bunched by hand and line skidded to a landing outside the stand.

The required removal of all cut stems 3 inches and larger at the stump was intended to encourage maximum product recovery by operators. Any stem 3 inches in stump diameter will usually yield a "grape stake" or agricultural stake product, and therefore is "commercial" for roundwood product utilization. However, because of poor local market demand and the long distance from many of the units to a viable market, product recovery was limited. Several operators preferred or chose to simply pull the required material from the stand and stack it for disposal. Consequently, the analysis is based on costs that include removal of much material not utilized for products (even though potential products existed). To provide a clearer picture of economic feasibility, actual treatment cost and product recovery information is supplemented by estimated costs if only recovered products are removed, and by estimating potential rather than actual product recovery. The best estimate of economic feasibility for a stand is obtained by comparing costs involving only recovered product removal to values of potential product recovery.

Because material removal requirements affect harvest costs and product recovery, the analysis of costs and values focuses on three questions:

1. What was the actual cost of harvesting and product value recovered under prescribed study conditions?

2. What is the probable treatment cost and potential value of products recoverable for the kind of stands represented, if removal of cut material is optional rather than required?

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3. How are costs affected by characteristics of the stand or harvest operation?

Stand Treatment Costs

Average actual stand treatment costs are summarized by harvest treatment in table 1. Actual treatment costs averaged $949 per acre in the 33 percent reduction units, $1,756 in the 66 percent reduction units, and $3,671 in the clearcut units. In individual harvest units, costs ranged from $317 per acre up to $3,986. These costs were developed using man and machine operating hours reported by operators (Hawkins this proceedings), multiplied by wage and machine rates judged to be about average for post and pole operators.

Table 1--Average actual treatment cost and estimated cost for thinning and product removal (stems >3 inches at stump) only, by treatment prescription[1]

Treatment	Actual cost, thinning and total removal of stems	Simulated cost, thinning and product removal only	Difference
	- - - - Dollars per acre - - - - -		
Basal area reduction (33 percent)	949	733	216
Basal area reduction (66 percent)	1,756	1,138	618
Clearcut[2]	3,671	2,032	1,639

[1]Based on 25 units for which cost and value data are available.

[2]Because of inadequate data, one clearcut area is not included in these averages.

Table 1 also shows a set of estimated costs (column 2), calculated by assuming that after felling the trees the operator removed only those considered as commercial products. As might be expected, these costs are considerably less than actual treatment costs because removal costs for the other (nonproduct) material were quite high, given the research study requirements imposed. The "difference" column in table 1 is an estimate of how much more it cost to achieve the removal of additional or nonmerchantable material. A detailed analysis of the harvest operations and logging productivity is presented by Hawkins (this proceedings).

Cost data also were analyzed to consider variations in stand and other operating conditions. Regression analysis was used to estimate the effect on costs of such things as number of trees cut, tree size, and volume removed. Several models were tested that reflected different aspects of costs (felling, removal, and total costs per acre).

Although several statistically significant variables were identified in these analyses, they are not reported in detail here. In our judgment, the limited number of observations and extreme variations in the harvesting practices of individual operators make interpretation inconclusive and subject to conjecture. Several points from the analyses are worth noting, however. Felling costs averaged $815 per acre and (by coincidence) removal costs were also $815 per acre. This ratio is consistent with data from several other studies of harvesting small stems in which these two components each averaged about 40 percent to 60 percent of stump-to-landing costs. Felling costs per acre increased as the number of 3- to 7-inch diameter at breast height (d.b.h.) stems cut per acre increased. These stems were required to be removed, and generally were measured, limbed, and bucked into product pieces; these steps are included in felling costs.

In contrast, felling costs per acre were relatively low for stands that had a very high total number of stems per acre because many of these stems were less than 3 inches d.b.h. and required only felling. Felling costs per acre were also lower as volume per tree increased, reflecting the fact that larger trees generally mean fewer trees per acre. Removal costs varied widely among study units, and although larger volume per stem was associated with lower cost per acre, there was no significant relationship between costs and volumes or number of stems per acre removed.

Product Values

Actual product values recovered by operators averaged $314 per acre for the 33 percent reduction units, $714 for the 66 percent reduction units, and $1,461 for the clearcut units. The range for individual units was 0 to $2,130 per acre. Average values recovered for each treatment are summarized in table 2.

Table 2--Summary of actual and adjusted product values, by treatment prescription[1]

Treatment	Actual value recovered	Simulated stand value	Difference
	- - - - Dollars per acre - - - -		
Basal area reduction (33 percent)	258	451	193
Basal area reduction (66 percent)	588	1,082	494
Clearcut	1,209	1,635	426

[1]Source: Hawkins this proceedings.

Because of local market constraints and lack of interest by the contractors, product recovery was often substantially less than it could have been. Also, values can be affected by current local supply and other factors not directly related to the stand. To adjust for these variations and provide a more uniform basis for comparing potential current and future stand values, a product recovery model was used (Hawkins and Schlieter this proceedings) to derive an estimate of potential value available from each site. Tree form, size, and defect information developed from study sites was used in the model, and was combined with standard product specifications and average product prices to derive the adjusted value estimates also shown in table 2. The "difference" column is a measure of the added product recovery and value that operators failed to obtain. Erratic markets and lack of initiative by some operators undoubtedly accounted for a large part of this forgone product value.

The actual net values from the study (actual values minus actual costs) ranged from +$735 per acre for one unit to -$3,124 for another. Because of wide variations in costs and values that may have been due in part to study constraints and operator characteristics, the adjusted or simulated costs and values shown in tables 1 and 2 (column 2) may provide a better comparison of potential net values. On this basis, the estimated net value for the 33 percent removal averaged -$282 per acre, for the 66 percent units -$51 per acre, and for the clearcut units -$397 per acre. In my opinion, however, the values for the clearcut units are not representative because unnecessarily expensive equipment and operating procedures were used on some areas, resulting in abnormally high costs. In the 33 percent removal treatments, 3 of the 11 units had positive or near break-even net values; in the 66 percent treatment, 6 of the 11 units had positive or near break-even net values. For the areas included, it appeared that the net values were more favorable for the heavier thinning, probably because there were more larger merchantable stems available to offset the costs of cutting nonmerchantable dead and small stems.

Projected Future Timber Values

Growing time following harvest in 1983-84 was not long enough to make growth response measurements on residual stands created by the treatments. Therefore, to bring expected future stand values into this analysis, treated stands were "grown" through time using the LPGRO model (Cole this proceedings). This model is based on stand age, site, and stocking and provides a quantitative and systematic estimate of future stand growth that can be used as a basis for comparing treatments. Actual stand response may, of course, vary from predicted values because of many uncertainties. Projections, therefore, were kept as simple as possible and were intended to answer the following questions:

1. What will be the net value of thinned stands if they are held for about 40 years without further intermediate thinnings?

2. What would be the value of these stands if they were harvested at the culmination of mean annual increment (MAI) when this is projected to occur at more than 40 years in the future?

3. What would be the value of these stands if instead of being thinned now they were held for 40 years without thinning and then harvested?

Future timber values, management objectives, and costs may change over time, but a basic measure of future stand values was assumed. Expected future volumes were converted to net values using costs estimated from various studies and appraisal guides, and wood prices of $125/1,000 bd ft of sawlogs and $0.50/ft^3 for smaller material used for roundwood products (1983 dollars).

Projected future costs and values are summarized in table 3. The 33 percent reduction units have a projected net value of -$280/acre in 40 years. If these stands were allowed to reach culmination of MAI, however, they are nearer to a break-even operation than if harvested 40 years hence. The 66 percent reduction units are projected to have a positive net value in either case. If the stands were allowed to grow to culmination of MAI, they would have nearly four times the net value they would have if harvested 40 years hence. The culmination of MAI for both treatments would occur about 55 years hence on average. In both cases, the gain is in the projected values, which increase more than the increase in harvest costs.

Table 3--Projected future harvest costs and value of thinned stands at 40 years in the future or at culmination of mean annual increment (MAI) (in 1983 dollars)

Unit thinning level and projection	Product value[1]	Harvesting cost[2]	Net
	- - - Dollars per acre - - -		
33 percent basal area reduction units:			
40 years	2,353	2,633	-280
MAI	2,655	2,758	-103
66 percent basal area reduction units:			
40 years	1,981	1,886	+95
MAI	2,571	2,205	+366

[1]Estimated at $125/1,000 bd ft sawlogs and $0.50/ft^3 for smaller roundwood products.

[2]Estimated from various harvest cost data. Detailed data on file at Forestry Sciences Laboratory, Missoula, MT.

In table 4 these units are projected as if no thinning had occurred now, but rather they were harvested in 40 years or at culmination of MAI. Culmination of MAI was generally 50 or 60 years hence. In this simulation, all the projected net values are negative by about the same amount (-$800 to more than -$900/acre).

Table 4--Projected future harvest costs and values of thinned stands, if no thinning had occurred and the stands were clearcut 40 years in the future, or at culmination of mean annual increment (MAI) (1983 dollars)

Unit thinning level and projection	Value	Cost	Net
	- - - Dollars per acre - - -		
33 percent basal area reduction units:			
40 years	2,645	3,559	-914
MAI	2,690	3,578	-888
66 percent basal area reduction units:			
40 years	2,552	3,496	-944
MAI	2,677	3,509	-803

The stand projections used in these analyses were developed by Hungerford (this proceedings). The relationship of stocking, volume, and growth for a typical unit (Corduroy Creek East) is shown in figure 1. In this example, in 40 years the projected merchantable volume if unthinned (6,070 ft^3/acre) would be greater than in the projected thinned stand (4,760 ft^3/acre). However, the net value of the thinned stand is greater because the merchantable volume is concentrated on fewer stems. Values are greater and harvesting costs are reduced considerably, resulting in a net value of +$208/acre at 40 years hence as compared to -$670/acre for the unthinned stand. In addition, the thinned stand reaches culmination of MAI in 60 years, and would have nearly twice the net value as the thinned stand would have in 40 years.

The previous tables and discussion have summarized the costs and values that might result from the studied harvesting alternatives in overstocked lodgepole stands. These alternatives can be compared by combining the current and projected future values as shown in table 5. The current values shown are derived from tables 1 and 2. The future net values are from tables 3 and 4, using the net values for harvesting stands at culmination of MAI (harvest in 40 years could have been used). These net values were then discounted to the present using a 4 percent discount rate.

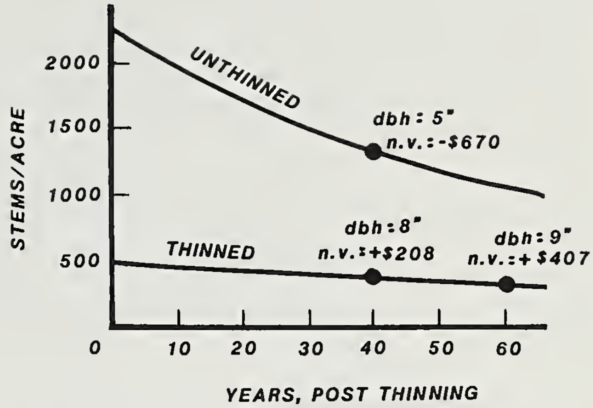

Figure 1--Projected stocking, average d.b.h., and net value for typical thinned and unthinned lodgepole pine stands.

Table 5--Summary of net dollar values for alternative treatments of sample stands, using simulated costs and values. Thinning or harvest at culmination of mean annual increment (MAI)

Study treatment and projection	Current net value	Discounted present value of future stand net value	Total current discounted net value
	- - - - Dollars per acre - - - -		
33 percent basal area reduction units:			
Thinned	-282	-30	-312
Not thinned	0	-125	-125
66 percent basal area reduction units:			
Thinned	-56	+29	-27
Not thinned	0	-79	-79
Clearcut units	-397	[1]0	-397

[1]Units clearcut now would have some young growing stock stands established, but their management and projected values are not included in this analysis.

This summary indicates that although none of the alternatives has a positive discounted current

net value, the 66 percent units are nearest to being a break-even operation. Because this average represents considerable variation in both current and projected future net values, even the "best" options may or may not be considered economically viable on an individual stand basis.

These net values illustrate that current harvests and expected future harvests should be approached as two separate parts of the problem of managing these stands. The differences in initial thinning values and the expected response and future net values may pose a tradeoff for managers to consider in setting a level of thinning and in specifying harvesting requirements such as slashing or removal of nonmerchantable material. Part of that management decision will probably involve considerations other than harvesting and product values.

NONTIMBER CONSIDERATIONS

At the start of the STEM program, managers indicated their concern over how to manage overstocked lodgepole to produce timber crops, and the costs of doing so. They also cited the need to protect or improve nontimber resources and to incorporate in decision making related management considerations such as risks from fire, disease, and damage.

Esthetic Considerations

One important nontimber concern of managers is the visual resource. Much of the lodgepole pine type is at middle to high elevations in mountainous areas and frequently forms the forest background and setting for outdoor recreation activities such as hiking and camping. To determine the effect of harvest treatments on the visual resource, two evaluations of harvest treatments in lodgepole pine areas were made. Landscape architects rated the areas, and the Scenic Beauty Estimation (SBE) technique (Daniel and Boster 1976) was used to measure viewers' preferences for different scenes. This method consists of taking color slide photos of forest scenes and having viewer groups rate the slides on a like-dislike scale. Although this does not measure scenic beauty in an absolute sense, it provides an interval-like measurement that is useful for comparing different scenes.

In this study, 11 scenes were evaluated, including three 66 percent units, two 33 percent units, and other scenes that were not part of the sample harvest units but are common conditions in lodgepole areas--clearcuts, mechanical thinnings, commercial thinnings, and uncut areas. Four different viewer groups rated the areas, but there were only minor differences among groups, so the results given here are based on combined ratings.

Scenic Beauty Ratings--The viewer group ratings for the 11 scenes are shown in figure 2. The SBE technique expresses preferences relative to a base area. In this case, the forest-meadow edge scene, usually considered a pleasing pastoral scene, is the base and all other areas are compared on a "dislike" basis. The mechanical thinning area was disliked the most, relative to the meadow edge scene. The Echo Lake 66 percent basal area reduction unit was disliked relative to the meadow edge, but ranked higher than most other treatments evaluated. The position of the bars in figure 2 indicates the relative preference among areas. Most thinning units were intermediate in scenic beauty ratings.

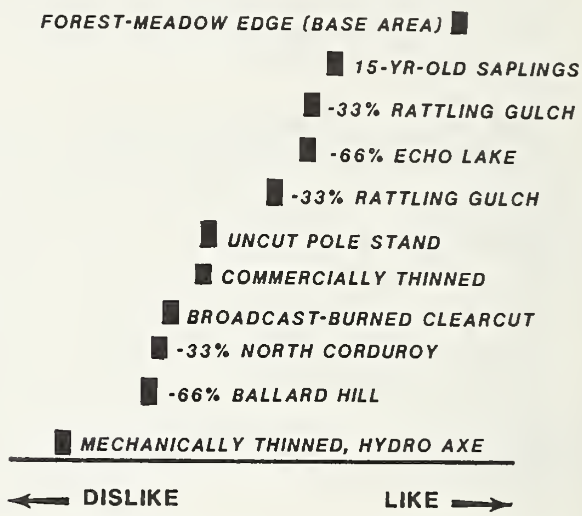

Figure 2--Scenic Beauty Estimation ratings by viewers of color slides of various treatments in lodgepole pine stands.

Because ratings differed, even among areas with similar treatments, regression analysis was used to try to explain differences in terms of physical-visual characteristics, such as number of trees, size of trees, and amount of slash. These characteristics were measured or estimated from the color slides and used as explanatory (independent) variables; the SBE score for each slide was used as the response (dependent) variable. Analyses were made for individual groups and combined groups using alternative regression models. Results were highly variable, but several characteristics appeared to be fairly consistent in their association with preference scores. Greater amounts of green groundcover vegetation under the stand were consistently associated with higher preference ratings, as were larger diameter leave-trees for some of the viewer groups. Down slash, bare and disturbed ground, and large numbers of small (<3 inches d.b.h.) trees appeared to detract from ratings.

Visual Quality Objective (VQO)--In addition to having viewer groups rate the areas, the same slides were shown to landscape architects who were asked to rate the slides as to the Forest Service visual quality objective (USDA Forest Service 1974) category they thought it represented (assuming they were passing by the areas in a car or on foot, and in a general timber growing zone). The VQO classification of the 11 areas

was as follows, with the ranking of SBE ratings in parentheses:

VQO class	Area and SBE ranking
Retention (management not evident)	Meadow-forest edge (1st) Uncut stand (7th)
Partial retention (management activities subordinate)	15-year saplings (2d) Two -66 percent units (3d, 4th) Both -33 percent units (5th, 9th) Commercially thinned area (6th)
Modification (management evident, but borrows from visual form)	One -66 percent (10th) Broadcast-burned area (8th) Mechanically thinned area (11th)

This indicates that, with proper slash treatment, thinned lodgepole stands can meet partial retention, a common objective in timber growing areas, but treatments, such as the mechanical thinning or burning, that leave slash and disturbance, should be avoided in viewer-sensitive areas.

Other Considerations

Several other studies of nontimber considerations were made as part of the posttreatment evaluation of harvest areas, and to some extent they indicated that tradeoffs are involved when evaluating thinning intensity and related harvesting concerns. For example, Lyon (this proceedings) found that uncut stands or light thinning preserved hiding cover for wildlife, but Hungerford (this proceedings) noted that more vigorous disturbance and opening up the stand may be needed to prevent loss of some browse species. In this case, two different aspects of a single resource, wildlife habitat, are involved, as illustrated in figure 3.

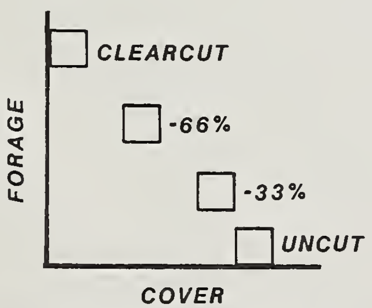

Figure 3--Tradeoff between wildlife forage and cover at different harvesting intensities.

Managers are also concerned about the risk to the investment made in the residual stand. Evaluations 2 years after treatments (Schmidt and Barger this proceedings) indicated that wind and snow losses in uncut (control) stands are virtually 0, but averaged about 1 percent in -33 percent units and more than 3 percent in -66 percent units. Additionally, losses to windthrow in the residual stand of treated units adjacent to clearcuts were as much as 47 percent. Here the tradeoff to be considered is between greater value growth response in -66 percent thinnings and the probability of greater losses through weather agents, as portrayed in figure 4.

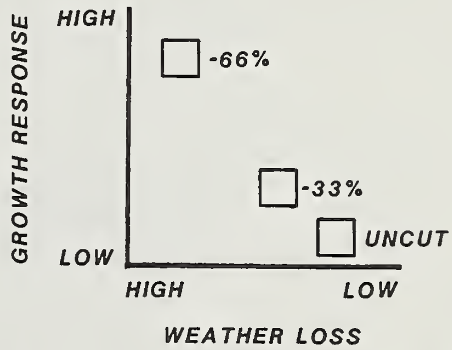

Figure 4--Tradeoff between timber volume growth response and weather loss at different harvesting intensities.

Brown and Johnston (this proceedings) indicate that the potential for suppression of wildfire in thinned stands is probably related more to level of slash removal than thinning intensity. Removal of larger (3-inch+) slash was estimated to reduce fireline intensity by half; in addition, Lyon (this proceedings) indicated that this level of slash removal would largely remove any barriers to big game movement. However, as noted earlier, the removal of nonmerchantable material represented a cost that made the difference between a net return versus a net loss for some units in the study. There appears to be, therefore, a multidimensional tradeoff involved that includes level of thinning, level of slash removal, and both near- and long-term effects on management risks and nontimber concerns.

CONCLUSIONS

The 25 pole-size, overstocked stands of lodgepole pine that were treated in the harvesting studies were selected because they were considered typical of the range of stands managers might consider for treatment with thinning to recover potential product values. Several units were also clearcut to provide a comparison with thinning treatments.

Results from treating these stands indicate there is a narrow, critical range of conditions that determine whether or not treatment is economically feasible. Lodgepole pine stands are usually considered a rather uniform, simple forest system, with a single tree species and only a few habitat types representing vast areas. However, the range of diameters and stocking represented in the study area stands resulted in certain cases where product recovery was high enough, and thinning

and slash treatment costs low enough, to create a profitable or at least break-even situation. Other areas that were physically similar, but with somewhat lower product values, have treatment costs higher than present product values, and even with some growth response projected for the residual stand do not appear to be an economically viable harvesting chance.

Some nontimber resources will benefit from thinning treatments, especially after some years of vegetative regrowth, but there are also tradeoff costs, such as an unavoidable period when weather or risk of fire threatens the "investment" (the residual stand).

It appears, therefore, that investment in thinning lodgepole pine stands like those represented in this study may require very close scrutiny to determine whether short-term and long-term timber values and changes in nontimber resource values come together to make intermediate thinning a wise or unwise management option. Unlike some management situations where large timber and high nontimber values guarantee a "black ink" operation, these lodgepole stands probably have to be considered on a stand-by-stand basis. Stocking, site potential, products, and even operator efficiency should all be part of the decision process. The economic costs and values, and the nontimber concerns discussed in this paper, should be viewed as possible choices and outcomes; each individual stand, however, will have its own outcome.

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Includes 22 reports of research sponsored by the Systems of Timber Utilization for Environmental Management Program relating to evaluating management alternatives for small-stem natural stands of lodgepole pine.

KEYWORDS: *Pinus contorta*, stand characteristics, management issues, silviculture, harvesting economics, harvesting systems, products, utilization, response to management, nontimber resource effects

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